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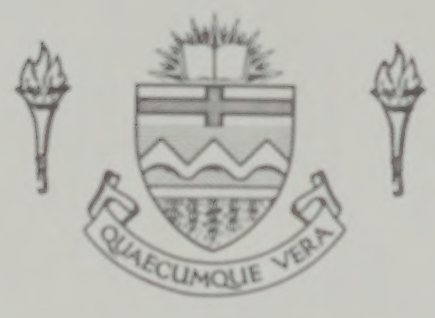

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- As studied over a three month period during which the mandibular third molars were extracted

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MANDIBULAR RESTING INTERPROXIMAL CONTACT FORCE

-as studied over a three month period during which

the mandibular third molars were extracted

BY

ALLAN HENRY GRAAS

A THESIS

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DEDICATION

I would like to dedicate this project to my wife Bev and my three children, Jennifer, Cheryl, and Jonathon as the time expended on this continuation of my education should rightfully have been theirs.

ABSTRACT

Electronic instrumentation consisting of a load cell, load cell conditioner, and strip chart recorder was used to measure the force required to withdraw a stainless steel strip from the interdental contact of the mandibular first molar and its most mesial proximal neighbour. From these measurements resting interproximal contact forces for each contact point were calculated. IPF's for each quadrant were determined one month prior (T_1), immediately prior (T_2), one month after (T_3), and then again two months after removal of the subjects mandibular third molars (T_4). Measurements were taken in 57 mandibular quadrants of 29 subjects. The mandibular third molars had at least 10% of anticipated root formation complete but still had apical root morphology consistent with incomplete root formation (i.e. an open root apex).

Results indicated no significant difference between right and left resting IPF for any of the test times. No significant difference between the resting IPFs of T_1 and T_2 or T_3 and T_4 were reported. The mean presurgical resting IPF was 624.23 gms and the mean postsurgical resting IPF was 402.2. The mean difference was 222.03 grams. It was concluded that there was a significant reduction in resting IPF associated with the surgical removal of mandibular developing/erupting third molars.

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LIST OF ABBREVIATIONS

1. ACF - Anterior component of force

2. IPF - Interproximal contact force

3. rdiff - The difference between mean right side pre and postsurgical resting IPF.

4. ldiff - The difference between mean left side pre and postsurgical resting IPF.

5. cdiff - The difference between mean presurgical and postsurgical resting IPF.

Chapter 1

Introduction

Mesial drift of teeth in humans has been extensively studied. Various longitudinal model analysis and implant studies[1,2,3,4,5,6] have provided a scientific basis for the concept that mesial drift does occur in humans. The magnitude of the movement, as compensation for interproximal wear, has been reported to vary from 72μ/year in Australian aborigines[7] to 8μ/year in contemporary young adults on a Western type diet[8].

The origin of the force(s), collectively referred to as the anterior component of force (ACF), that result in the mesial migration of human teeth is however far from settled. Forward movement of the buccal teeth was thought to be initiated by the forces of the cheeks and tongue[9,10]. Scar tissue has also been discussed as causing the movement of teeth on either side of a space made by extraction[11]. Contraction of the trans-septal fibres between teeth has also been implicated as causing mesial drift[12,13] in humans. The anterior component of the force of mastication and its role in the mesial migration of teeth has also been discussed[11,14]. Selective apposition of bone on the distal wall of each alveolus has also been implicated as being responsible for the mesial movement of teeth[15].

Two of the more recent investigations[16,17] into mesial tooth migration indicate that the cause of mesial drift is

multifactorial. Removal of interproximal contacts in combination with removal from occlusion did not inhibit mesial migration of the affected teeth. Selective occlusal grinding in combination with removal of approximal tooth contacts illustrated that the anterior component of occlusal force merely affected the rate of mesial drift. Other factors affecting mesial drift were tooth inclination and occlusal plane inclination.

The impaction, or even the eruption, of mandibular third molars has also been implicated as being responsible for the generation of an increased mandibular anterior component of force[17,18,19]. If an increased anterior component of force ("the force from behind")[20] was associated with mandibular developing/erupting third molars, and was of a sufficient magnitude, it could result in anterior migration of teeth. If this migration was not compensated for by interproximal tooth wear tooth malposition could result. Using this reasoning a small number of researchers[20,21,22,24] have suggested that mandibular third molars are related to lower anterior relapse in orthodonticaly treated cases. Rightly or wrongly many individuals are subjected to the removal of their mandibular third molars in order to enhance the stability of their orthodontic treatment result[18]. This occurs without conclusive evidence for the existence of an anterior component of force attributable to mandibular developing and erupting third molar teeth[23].

a. Statement of the Problem

The role of mandibular developing/erupting third molars in the etiology of lower anterior tooth malalignment has yet to be determined. If developing/erupting mandibular third molars are a cause of lower anterior tooth malalignment the presence of a mesial force generated by the development/eruption of these teeth could represent the mode of action. The inability to demonstrate this force would cause one to reconsider the above relationship. Unfortunately even if a mesial eruption force could be demonstrated the degree to which this force contributes to lower anterior crowding would still remain questionable.

b. Purpose of the Study

The objective of this study was to quantify changes in the resting interproximal contact force associated with the removal of mandibular developing/erupting third molar teeth. Interproximal contact force changes reflect changes in the mesial force associated with the removal of developing/erupting mandibular third molars. The interproximal contact force was studied over a period of approximately four months during which the mandibular third molars were removed.

Developing mandibular third molar teeth were defined as teeth having completed at least 10% of anticipated root formation. Erupting mandibular third molars were defined as teeth having apical root morphology consistent with incomplete root

formation (i.e. open apex). The teeth were not in functional occlusion.

c. Research Questions

1) Do mandibular developing/erupting third molar teeth make a significant contribution to the resting interproximal contact force?

2) Is the amount of the contribution to the resting interproximal contact force related to the age or gender of the individual?

3) Is the amount of contribution to the resting interproximal contact force related to the angle of impaction, depth of impaction or stage of root development of the associated mandibular developing/erupting third molar?

4) Is the amount of the contribution to the resting interproximal contact force related to a previous history of orthodontic treatment or the absence of any teeth in the arch?

5) Does the resting interproximal contact force vary significantly in an individual (whose dental restorative status is unchanged) over a two month time period?

6) Does postsurgical resting interproximal contact force vary significantly in an individual over the immediate two months following mandibular third molar removal?

7) Is the change in resting interproximal contact force associated with the surgical removal of mandibular third molar teeth related to the surgeon removing the teeth?

d. Hypotheses

1) H_o! There is no significant change in the resting interproximal contact force associated with the surgical removal of mandibular developing/erupting third molar teeth.

H_a! There is a significant change in the resting interproximal contact force associated with the surgical removal of mandibular developing/erupting third molar teeth.

2) H_o! The change in the resting interproximal contact force associated with the surgical removal of mandibular developing/erupting third molar teeth is not significantly related to the age of the individual.

H_a! The change in the resting interproximal contact force associated with the surgical removal of mandibular developing/erupting third molar teeth is significantly related to the age of the individual.

3) H_o! The change in the resting interproximal contact force associated with the surgical removal of mandibular developing/erupting third molar teeth is not significantly related to the gender of the individual.

H_a! The change in the resting interproximal contact force associated with the surgical removal of mandibular developing/erupting third molar teeth is significantly related to the gender of the individual.

4) a. H_o! The change in the resting interproximal contact force associated with the surgical removal of mandibular developing/erupting third molar teeth is not

related to the angle of impaction of the tooth.

H_a! The change in the resting interproximal contact force associated with the surgical removal of mandibular developing/erupting third molar teeth is significantly related to the angle of impaction of the tooth.

b. H_o! The change in the resting interproximal contact force associated with the surgical removal of mandibular developing/erupting third molar teeth is not related to the depth of impaction of the tooth.

H_a! The change in the resting interproximal contact force associated with the surgical removal of mandibular developing/erupting third molar teeth is related to the depth of impaction of the tooth.

c. H_o! The change in the resting interproximal contact force associated with the removal of mandibular developing/erupting third molar teeth is not related to the stage of root development of the tooth.

H_a! The change in the resting interproximal contact force associated with the removal of mandibular developing/erupting third teeth is related to the stage of root development of the tooth.

5. H_o! The change in the resting interproximal contact force associated with the surgical removal of mandibular developing/erupting third molar teeth is not significantly related to a history of previous orthodontic treatment.

H_a! The change in the resting interproximal contact

force associated with the surgical removal of mandibular developing/erupting wisdom teeth is significantly related to a history of previous orthodontic treatment.

6. H_o! The change in the resting interproximal contact force associated with the surgical removal of mandibular developing/erupting third molar teeth is not significantly related to the absence of any other teeth in the arch.

H_a! The change in the resting interproximal contact force associated with the surgical removal of mandibular developing/erupting third molar teeth is significantly related to the absence of any other teeth in the arch.

7. H_o! Resting interproximal contact force does not vary significantly in an individual (whose dental restorative status is unchanged) over a two month period of time.

H_a! Resting interproximal contact force does vary significantly in an individual (whose dental restorative status is unchanged) over a two month period of time.

8. H_o! Postsurgical resting interproximal contact force does not vary significantly in an individual over the immediate two months following mandibular third molar removal.

H_a! Postsurgical resting interproximal contact force does vary significantly in an individual over the immediate two months following mandibular third molar removal.

9. H_o! The change in resting interproximal contact force associated with the surgical removal of mandibular

developing/erupting third molar teeth is not significantly related to the surgeon removing the teeth.

H_a! The change in resting interproximal contact force associated with the surgical removal of mandibular developing/erupting third molar teeth is significantly related to surgeon removing the teeth.

Chapter 2

LITERATURE REVIEW

a. Third molars and lower incisor crowding

The relationship between mandibular third molars and lower anterior crowding has been extensively researched and reported on in the orthodontic literature over the past one hundred years. Over the years several investigators have reported a positive correlation between mandibular developing/erupting third molars and the occurrence of lower anterior crowding in the mid to late teens and early adulthood.

Vego[25], in a longitudinal study of dental models, attempted to quantify the influence of the lower third molars on loss of arch perimeter and to study the relationship between tooth size and the congenital absence of mandibular third molars. Two non-orthodonticaly treated groups whose records were taken from the Bolton Study were compared. One group of twenty five had congenitally missing lower third molars and a second random group of forty cases was selected with complete dentition (i.e. including the wisdom teeth) lower arches. An individual's casts were made twice; first, after the eruption of the second molars, and second, at an age past seventeen. The mean interval between measurements was 5 years and 6 months. No measurement error was reported.

In the sixty-five cases studied the arch perimeter was measured according to Lundstrom[26]. The arch perimeter showed a decrease from the first to second models. The reported mean

arch perimeter loss for the group with third molars was 2.5 mm with a range of 0.3 mm to 7.6 mm with the standard error of the mean being 0.26 mm. The mean arch perimeter loss for the group missing third molars was 1.7 mm. There was a range of 0.2 mm to 4.0 mm. The standard error of this mean was 0.19mm. The 0.8 mm difference in average arch perimeter loss was significantly different at p = .02. The difference in tooth size between the two groups was not found to be statistically significant. This is in agreement with a study by Forsberg[27] that found no association in males between the surgical removal of mandibular third molars and the size of teeth in a dental arch. Given the results reported both Forsberg and Vego noted a multifactorial etiology of late crowding in the lower arch.

Bergstrom and Jenson[28] also investigated the role of the mandibular third molar in secondary crowding of the lower arch. In this cross-sectional study of 60 dental students, 27 had unilateral aplasia of the mandibular third molar. Measurements were taken of the individuals dental models and a left-right comparison of the space conditions on both sides of the arch made. Any displacement of the midline and mesiodistal asymmetries of the lateral segments were also noted. The results suggested that there was greater crowding (0.64 mm) in the quadrant with the third molar than in the quadrant with the third molar missing (statistical significance not reported). There was a definite mesial

displacement of the lateral segment of the side of the third molar in the mandible. The presence of a mandibular third molar seemed not to affect the midline. They found no evidence of a correlation between age and the degree of crowding or mesial tooth displacement. They concluded that the presence of a third molar appeared to exert some influence on the development of the dental arch, but not to the extent that would justify either the removal of the tooth germ or the extraction of the third molars other than in exceptional circumstances.

Keene[29], in a cross-sectional study done on 195 caries resistant naval recruits similarly studied mandibular third molar agenesis, spacing and crowding of mandibular teeth, and mandibular lower first molar mesiodistal tooth width. Crown diameters were quantified using sharpened sliding vernier callipers. Crowding was defined as overlapping of proximal surfaces or buccolingual displacement of one or more teeth because of insufficient space in the arch. Spacing was defined by the presence of regularly arranged teeth with one or more spaces between the proximal surfaces of the teeth.

He found well aligned or spaced teeth in 75% of the recruits exhibiting bilateral agenesis of their mandibular third molar teeth. In recruits with both mandibular third molars present this condition was found only 50% of the time. Crowding was found in 50% of later group while only in 25% of the former group. The association of the absence of mandibular third

molars with a smaller degree of crowding was explained by a similar association with smaller mandibular first molars (mean difference of 0.3 mm).

Schwarze[22] compared cross-sectional model analysis data obtained from 105 orthodonticaly treated patients 56 of whom had mandibular third molar teeth removed at ages ranging from 12 to 22 years. The remaining 49 patients served as nonextraction matched controls. He demonstrated that the mandibular lower first molar in the control group was carried forward by an average of 1.5 mm more than in the extraction group. His conclusion was that the more frequent crowding of anterior teeth in this group resulted from the sagittal force exerted by the presence of mandibular third molars.

The Belfast Third Molar Study[30,31,32,33] utilized a group of 51 non orthodonticaly treated subjects (22 females, 29 males) with intact lower arches and bilateral third molars present. The subject's records consisted dental models, 60 degree (rotated right and left) lateral cephalograms and 90 degree lateral cephalograms taken at average ages of 13 and 18 years. The mesiodistal dimensions of the teeth and the arch perimeter were measured with a Baker Vernier Microscope. The serial cephalograms were traced and the mandibles superimposed on mandibular structures according to Bjork. Antero-posterior changes of the lower first molar were measured along the palatal plane while the mandibles were superimposed.

On average these cases had an increase in lower arch crowding

of slightly more than 1mm on each side during the 5-year observation period. In some quadrants the crowding increased by as much as 4mm (range of -0.35mm to 4.08mm) and only 16% of quadrants demonstrated no change in crowding.

Using these records Richardson[30] performed a correlation analysis of various changes including lower arch crowding, position of the mandibular first permanent molar as well as angular and linear positions of the mandibular incisors from 13 to 18 years. A significant positive correlation was found between increased crowding and mesial movement of the lower first molar ($r=0.47$ $p=0.05$). This increased crowding was correlated with antero-posterior and angular changes in lower incisor position. The lower incisors were found to procline (mean = 1.08 degrees, s.d. = 3.49 degrees) over the of the study.

Also using data from the Belfast third molar study Richardson [33] tried to correlate the role of facial morphology and changes in facial morphology brought about by growth or orthodontic treatment with the development of late lower arch crowding. The radiographic measurements of facial morphology included Ar-Pog, Go-Pog, Ar-Go, Mx plane-Me, OB, gonial angle, ANS-PNS/Go-Me and interincisal angle. The difference between arch length and total tooth size from first molar to first molar (i.e. space condition) was measured from models taken at the beginning and end of the data collection time frame. No strong or consistent relationships were found between the

occurrence of late lower arch crowding and changes in facial morphology or the presence of certain morphological features.

In a companion study Richardson[31] investigated the effects of lower second molar extraction on lower anterior crowding over a similar period of five years. Space condition (arch perimeter minus tooth size) was measured with a vernier microscope on plaster models of the early permanent dentition (i.e. complete anterior to the first molar) and five years later. Radiographic change in the antero-posterior position of the lower first molar was also monitored by superimposing (on mandibular structures according to Bjork) 60 degree angulated left and right cephalometric radiographs taken at the same time as the dental models. The extraction group exhibited an average decrease in crowding of 2.7mm. A mean distal movement of the extraction group lower first molar as to the control group of 3.8mm was also seen. The sample size of the experimental group was very small (10). Nevertheless, she stated that "there may be some justification for extraction at the back of the lower arch as a prophylactic measure against the development of late crowding".

Richardson[32] also investigated the relationship between lower molar crowding in the early permanent dentition and various dimensions of the mandible using the same five year longitudinal data as before. The molar space was measured on a tracing film as the distance between the distal surface of the mandibular first molar and the junction of the anterior

surface of the ramus and body of the mandible projected onto a horizontal through the palatal plane. The size of the second and third molars were measured directly from the film. Molar crowding was defined as the difference between the two. She found that when molar crowding is present in the early permanent dentition, there is likely to be forward movement of the buccal dentition with an increase in lower arch crowding over the ensuing five-year period ($r = 0.32$, $p = 0.05$). She suggested that there was a transfer of crowding from the molar region to the front of the arch. She also concluded that there was an association between impacted lower third molars and molar crowding (defined as the difference between molar size and space available). She concluded that the space for the third molar was made, at least in part, by forward movement of the dentition, which may jeopardize the alignment of teeth anterior to the first molar. As the correlations were weak but significant ($r=.60$, $p=0.05$) it was concluded that other not identified factors were also involved in late lower anterior crowding.

In a longitudinal study of 52 teenagers (age range 13 to 19 years, mean 15.5 years) that underwent unilateral removal of bilaterally impacted mandibular third molars Lindqvist and Thilander[34] investigated the contribution of lower third molars to late lower anterior crowding. Over a three year comparison period 70% of the time they found a more favourable development of the arch alignment (i.e. less crowding) on the

extraction side. The comparison became more positive with time as was made evident by the analysis of 5 subjects that presented for follow up 5 years after termination of the control period. They were unable to predict which arches would react with favourable alignment changes subsequent to the removal of their third molars.

In spite of the preceding research there seems to be general lack of consensus as to the precise role of mandibular developing/erupting third molars in the development of lower anterior crowding commonly seen in the mid to late teens and early adulthood. In fact several researchers have published data which suggests third molars play very little, if any, role in long term dental arch changes.

Ades et al[35] reported on the role mandibular third molars played in long term alignment changes in the lower dental arch of 97 orthodonticaly treated patients. The sample consisted of four groups: premolar extraction treated, nonextraction treated, nonextraction treated (initial generalized spacing) and serial extraction untreated subjects. These groups were further broken down into subgroups of persons who had third molars that were either impacted, erupted into function, congenitally absent, or extracted at least ten years before the final records of the study were taken. Over the post retention time period studied (mean time interval was 13 years) it was shown that anterior tooth irregularity increased in all groups and subgroups. No significant differences in

incisor crowding were noted between the different subgroups.

Kaplan[36] similarly collected a sample of 75 orthodonticaly treated Caucasian patients an average of 9.3 years out of retention. Sixty three percent of the cases were extraction cases. They had a mean post-retention age of 26.6 years. Thirty patients had bilaterally erupted mandibular third molars, twenty had bilaterally impacted mandibular third molars, and twenty five had bilateral mandibular third molar agenesis. After examining pretreatment, end of active treatment and post-retention dental models and radiographs no significant differences were found in arch length, lower molar position, lower incisor position or axial inclination between the three groups. This study indicated that the presence of third molars was not associated with a greater degree of lower anterior crowding after the cessation of retention. It is interesting that the same data, when reworked with Student's t test by reviewers Vasir and Robinson[37], showed a significant difference (p value not reported) in the amount of crowding between the extraction orthodontic group and the other groups that was correlated significantly with the presence or absence of mandibular third molars. The presence of mandibular third molars was associated with 1.5 mm more crowding per arch than the extraction group. There were no reported differences between the subgroups in the nonextraction group.

Sampson et al[38] studied the development of mandibular dental arch crowding during the period of mandibular third molar

eruption and compared changes with the eventual status of the mandibular third molar. The sample consisted of 54 Caucasian subjects that had received no orthodontic treatment and had had no permanent mandibular teeth extracted. The sample was divided into three groups: erupted third molars, impacted third molars, and missing third molars (this group was too small to be included in final data analysis-i.e. 3 subjects). Dental models were made of the group at an average 13.3 years of age and then again at an average of 18.5 years of age. As no significant difference in crowding was noted between the erupted or impacted third molar groups the authors concluded that third molar impaction was an effect of dental arch crowding, rather than a prime etiologic factor. They noticed no strong correlation between mandibular growth rotation (measured as changes in the angle GoGn/SN) and anterior crowding.

Bjork and Skieller[6], in a mixed longitudinal implant study on patients ages 9 to 20, also studied on late anterior crowding in the lower arch. They noted that in most cases studied there was a shortening of both dental arches, but this was manifest before the roots of the third molars had appreciably developed. They thought that the shortening of the arches was to some extent due to pressure exerted by the erupting second molars. Their study subjects were all within three years of their peak pubertal condylar growth. They concluded that the role played by the third molars in this

reduced arch could not be reliably judged until completion of jaw growth and root development.

b. Third molars and resting interproximal contact force

In 1961 Osborn[39], utilizing ten subjects, measured the interdental force between adjacent teeth in the same arch during contraction of the masticatory muscles. He was studying the role that the anterior component of occlusal force might play in mesial tooth drift. The anterior component of occlusal force was determined by measuring the difference in the force required to withdraw a stainless steel strip from between interdental contact points during clenching and with the teeth apart.

Interproximal contact force (IPF) was related to the frictional force (f) that resisted withdrawal of a matrix strip by the formula:

$$IPF = f/2\mu \text{ (Newtons)}$$

where μ is the coefficient of friction between tooth enamel and stainless steel. Using a spring balance (measurement error was not reported) he demonstrated a definite anterior component of occlusal force. This was indicated by an increased IPF measured mesial to the mandibular first molar. The anterior component of occlusal force (generated by clenching on a posterior bite block between the mandibular and maxillary second molars) exhibited an exponential rate at each contact point as one progressed anteriorly.

In 1989 Southard et al[40] reported a study in which they designed and developed electronic instrumentation to measure the interproximal resistance forces generated by a single tooth under a known axial load. They also quantified the distribution and dissipation of this force as it progressed anteriorly. The accuracy of their interproximal contact force measurement system was reported to be ± 45 grams. They found μ to be equal to .145 (S.D.=.02) which was in close agreement to Osborn's reported value of .165. They confirmed the presence of an anterior component of occlusal force when a person generated a 20 pound bite force between the upper and lower second molars unilaterally. The interproximal contact force dissipation distribution approximated exponential decay functions. The interproximal contact force distribution around the arch remained consistent under reduced loads. Resting IPF was reported to remain relatively constant between test days.

In a follow up article Southard et al[41] investigated the relationship between resting IPF and dental malalignment. Three groups of five subjects were formed on the basis of the extent of mandibular anterior malalignment. Group 1 had an Irregularity Index[42] of <2mm, group 2 an Irregularity Index of >2mm but <4mm, group 3 an Irregularity Index of >4mm. A correlation ($r = .53$, $p = 0.05$) was revealed between resting interproximal contact force and dental malalignment of the mandibular incisors. The potential significance of parafunctional habits, vis a vis an increased anterior

component of force, and development of mandibular anterior malalignment was also noted.

Southard et al[23] have similarly investigated the mesial force from unerupted mandibular third molars. Twenty patients with bilaterally impacted lower third molars and an average age of 20.6 years were selected for this study. Resting mandibular IPF measurements were taken just prior to (subject in an upright position) and immediately following the unilateral surgical removal of a third molar (subject in a supine position). The nonextraction side served as the control. Resting mandibular IPF measurements were also taken in a group of ten individuals before and after lying down for 2 hours. In the surgical group resting IPF's were found to decrease (13.4% to 10.8%) on both the extraction and control sides respectively. No significant IPF difference was noted between the control and extraction groups. In the second group the mean interproximal contact force of all measured mandibular contacts decreased after the patient was moved from an upright to a supine position.

This is congruent with another study in the Southard series[43] that investigated the role played by in determining interproximal contact force. An adult sample of 5 men and 5 women (healthy periodontal tissues and complete dentitions) with a mean age of 29.5 years were used in this study. The subjects had resting IPF's calculated for both the upper and lower arches initially in an upright position, 2 hours later

in a supine position, and then again 2 hours later in an upright position. From the first to second tests the mean IPF decrease ranged from -32% to -10% depending on the contact point checked. Following the return to an upright position the mean IPF's increased from 20% to 8%. These changes were statistically significant.

c. Summary and critique of third molar studies

The influence of mandibular third molars on the alignment of the mandibular dentition is still controversial. Opinion regarding their etiologic role in lower anterior crowding has varied over the history of orthodontics.

Bishara and Andreason[44] in a 1983 review article concluded that late crowding of lower incisors is produced by many factors which include tooth size, tooth shape, narrowing of the intercanine dimension, retrusion of incisors, and growth changes occurring in the adolescent stages of development. In their opinion there is no conclusive evidence to indict third molars as being the major etiologic factor in the posttreatment changes in incisor alignment.

Bramante[45], in his 1990 review article on third molars and lower incisor crowding, concluded that the cause of post pubertal lower anterior crowding is multifactorial. He also

suggested that the third molars do not significantly influence the crowding of the lower anteriors.

Richardson[20] however, published a 1989 review article on the same subject and implicated pressure from the back of the arch and the presence of a third molar in the cause of late lower arch crowding. Care was taken not to preclude the involvement of other causative factors and she noted that the cause of late crowding may differ from one subject to another and there may be more than one factor contributing to the development of late crowding in any one individual.

The most recent review article on the mandibular third molar and late crowding of the mandibular incisors published by Vasir and Robinson[37]. They concluded that "if interpretation of data from the studies they cited (similar studies in all four review articles) was accepted, then the conclusion would be that the mandibular third molar has a statistically weak association with late crowding of lower incisors and that the process of eruption of third molars may be implicated in the mechanism of this crowding".

Studies dealing with the quantification of the mesial force generated by developing/erupting mandibular third molar teeth are in their infancy. The initial attempt by Southard et al[40] involved instrumentation with a reported in vitro accuracy of only ± 45.4 grams. The instrumentation was also reported to be very susceptible to temperature and humidity fluctuations. The physiologic variables affecting resting interproximal contact

force were poorly controlled in the experiments. Subjects were tested in various postural positions and the results directly compared. It is now known that posture affects resting interproximal contact force.

Chapter 3

MATERIALS AND METHODS

The parameters of the sample represented by the participants in this study and how they were chosen are described in detail following. This discussion includes the developmental and positional status of the participants mandibular third molars. The measurement instrumentation design and measurement procedure used for in vivo and in vitro calibration and data collection are also detailed. This is followed by a discussion of the descriptive and inferential statistics employed in the study.

a. Subject Sample

i. Subjects

The 105 subjects for this study were chosen from patients referred to the private practice office of the participating oral surgeons for evaluation and consultation regarding mandibular third molar removal.

The individuals that consented to both the surgery and the study were then screened into the study by the investigator according to the following four criteria:

1. The posterior segments were well aligned with a buccal segment modified Little's Irregularity Index[42] of less than 1.5mm.

2. The mandibular third molars of subjects had at least 10% of anticipated root formation complete but still had

apical root morphology consistent with incomplete root formation (i.e. an open root apex).

3. As determined from radiographic and clinical assessment, no overt signs of periodontal disease or abnormal tooth mobility (mobility index of <1) were present.

4. No new interproximal restorations in the buccal segments during the study period.

All those screened and determined to be acceptable did not complete the study. From T_1 to T_2 approximately 50 participants were lost. From T_2 to T_3 approximately 23 participants were lost and from T_3 to T_4 3 subjects were lost (for explanation of these T symbols see section b of this chapter). 29 subjects completed the study. All consenting subjects presented with a panoramic radiograph taken within the previous six months. Necessary approvals and consent forms were obtained (Appendix A). The distribution of subjects for age and gender are detailed in Table 1.

Age and Gender Distribution

AGE	Gender M	Gender F	Frequency	Percent
15	2	-	2	6.9
16	1	1	2	6.9
17	2	3	5	17.2
18	3	-	3	10.3
19	-	8	8	27.6
20	1	2	3	10.3
21	-	2	2	6.9
22	-	4	4	13.9
TOTAL	9	20	29	100.0

Table 1. Distribution of subjects for age and gender.

ii. **Third Molar Parameters**

The developmental and positional status of the mandibular third molar was quantified using three criteria: depth of impaction, angle of impaction, and stage of root development. These criteria, determined from the subjects panoramic radiograph, were used as independent variables in the data analysis.

To determine depth of impaction the occlusal plane was constructed on the panorex by drawing a line through the cusp tips of the molars and bicuspids. The depth of impaction was measured as the distance between the most occlusal portion of any part of the mandibular third molar and the occlusal plane measured along a line perpendicular to the mandibular occlusal plane.

The angle of impaction was determined by first drawing a "best fit" line through the long axis of the mandibular third molar. The distal aspect of the angle formed by this line and the occlusal plane (constructed as previously described) was measured as the angle of impaction. Thus the more horizontal the mandibular third molar impaction the lower the angle reported.

The stage of root development was determined according to Nolla[46]. The radiographic appearance of the mandibular third molar was compared to drawings and each tooth was given a developmental score according to the drawing that it most nearly approximated. If less than one third of the root had

completed formation the tooth was labelled a 6, if one third of the root had completed formation the tooth was labelled a 7, if two thirds of the root was completed the tooth was labelled an 8, and if the root had almost completed formation but still had an open apex it was labelled a 9. No half values were assigned. While Nolla's stages of tooth calcification range from 1 to 10 all the mandibular third molars in this study were such that they were categorized as either 6, 7, 8, or 9.

b. Measuring Instrumentation and Procedure

By measuring the force (f) required to draw a stainless steel strip between the proximal contact points to be measured and using the formula IPF = $f/2\mu$ (Appendix B) IPF's were calculated. These were determined one month prior (T_1), immediately prior (T_2), one month after (T_3), and then again two months (T_4) after removal of the mandibular third molar.

The contact point chosen for measurement was between the mandibular first molar and its mesial proximal neighbour. It was chosen because it represents the most posterior contact point easily measurable. Measurements were done in both right and left quadrants of the lower arch.

i. **Instrumentation System**

Three separate components consisting of a load cell, load cell conditioner, and a strip chart recorder made up the electronic portion of the measurement instrumentation.

The most significant improvement in instrumentation over previous IPF/ACF studies lies in the load cell used (Figure 1). The Omega LCF load cell[a], according to manufacturers specifications, is a precision miniature instrument that maintains excellent performance. For example, a 100% full scale load applied at 90 degrees to the base of the active stud would create a maximum error of only 1.5%. It is a tension/compression design with male thread studs for load attachment. To minimize or eliminate the effects of off axis loads, the LCF has two welded stainless steel diaphrams on the top and bottom side of the active element. This internal tripled stack design assures excellent long term stability. It is also temperature and humidity compensated. Manufacturers specifications indicate a measurement repeatability of ± 0.05% at full scale load. The load range of the cell used was from 0 - 1 kilogram.

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[a]Model LCF, Omega Engineering Inc., Stamford, CT., USA. 06907-0047

SPECIFICATIONS

SIGNAL OUTPUT: 2mV/Vnom.

LINEARITY AND HYSTERESIS: ±0.15%F.S.;LCF-500 ±0.2%F.S.

REPEATABILITY: ±0.05% F.S.

COMPENSATED TEMP RANGE: 60-160 DEG. F

SAFE OVERLOAD: 50% F.S.

ZERO BALANCE: ±2% max.

D - 0.75 in. H - 0.62 in. A - 0.31 in.

B - 0.19 in. C - 0.25 in.

Diagram of Load Cell

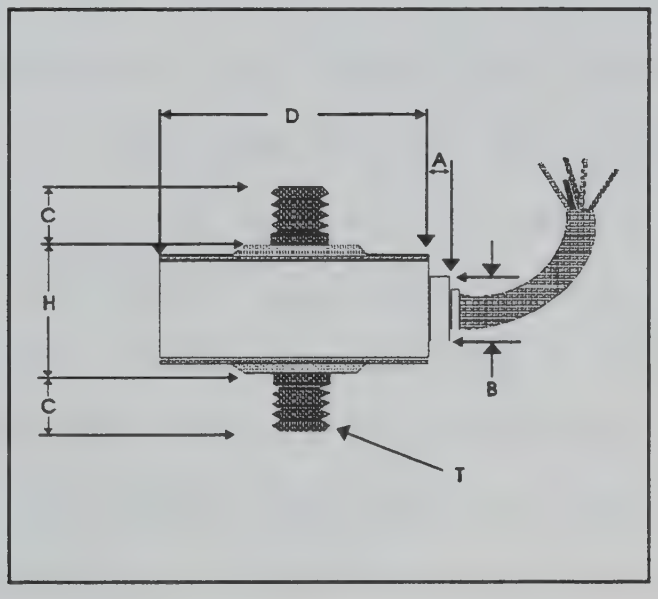

Figure 1. Diagram of load cell and manufacturers specifications.

The load cell was modified by the attachment of a screw on ring to one side and an active threaded male stud (with a 1mm diameter hole in the end farthest from the cell) to the other. The purpose of the ring was to facilitate manual handling of the cell. A 5 inch piece of 20 pound test nylon fishing line was threaded through the hole in the male active stud. The fishing line was subsequently threaded through the eyelet of a small fish hook and then knotted. The sequence of parts was fishing line, fishing hook, active male stud, and load cell (Figure 2).

The load cell was connected to a load cell conditioner manufactured by the University of Alberta, Mechanical Engineering Department. The conditioner provided accurate amplification and, with its balance and gain adjustments, allowed for adjustment at the zero and end of range loads.

A strip chart recorder[b] was connected to the load cell conditioner. On the graph paper of the recorder all force measurements were recorded within the designed scale.

The stainless steel strips drawn between the teeth were 5 cm by 5 mm and cut from 0.015 inch thickness shim-stock. Centred 2mm from one end 2mm diameter holes were drilled through which the fish hook was passed.

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[b]Model 585, Omega Engineering., Stamford, Ct. USA. 06907-0047

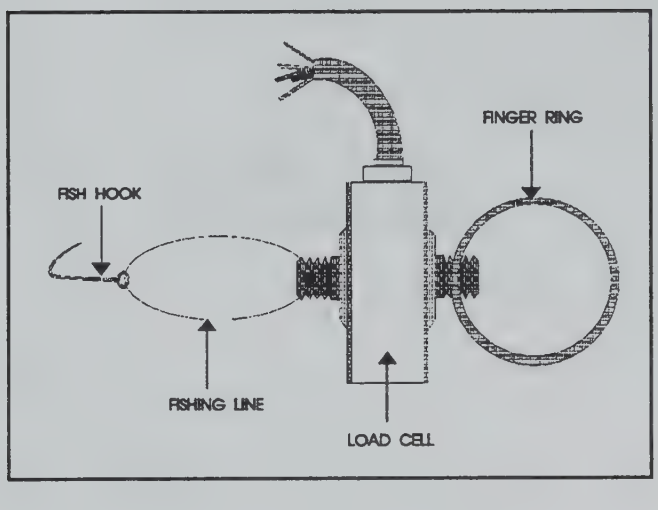

Figure 2. Sequence of parts of measuring device.

A flow chart of the IPF measuring, data amplification, and analysing system is given below (Figure 3).

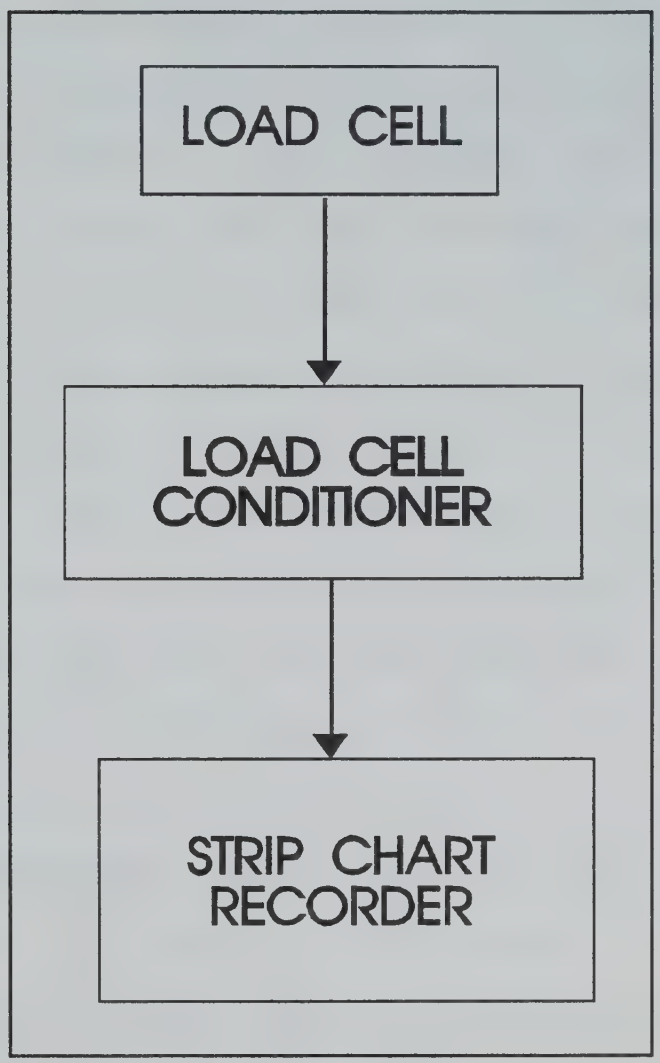

Figure 3. Flow Chart of analysing system.

ii. **Calibration**

With the instrumentation assembled and the power turned on, the load cell/fishing hook/line was suspended vertically from a fixed point and the balance lights adjusted to zero. The pen position of the strip chart recorder was then adjusted with the recorder zero adjustment knobs such that the pen tip lie centred on the right vertical line of the recorder's graph paper. A 200 gram weight was then suspended from the hook end of the measuring device and the gain and scale adjustment knobs on the load cell conditioner were adjusted to bring the pen of the recorder to the centre of the left vertical line of the recorder's graph paper. As the graph paper was divided into ten equal parts by eleven vertical lines, and each equal part was further divided into ten more equal parts by fine vertical lines, a conveniently calibrated (units of 2 grams) measuring scale was now provided. The scale chosen allowed for accuracy of measurement and yet also provided for a wide range of measurement to allow for variation in IPF between individuals. For subjects whose measurements were outside of this range the scale was easily changed to a 500 gram or 1000 gram scale.

To check for accuracy of measurement of the system various known weights (50, 100, 500, and 1000 grams) were hung from the measuring device and the recordings noted on the graph paper. The system under these static load conditions was

accurate to ± 2.0 grams within the calibrated range. Under zero load the recorder pen always returned to the centre of the vertical axis that was referenced as zero load. The measuring device was individually calibrated for each subject to reduce measurement error. See Appendix C for test data.

iii. **In Vitro Testing**

Two extracted lower molars, bicuspids and cuspids were mounted in plaster on labelled SAM articulator[c] mounting plates. Care was taken to mount the teeth in accurate interdental contact point relationships. The plaster was allowed to dry for 1 week. The articulator and mounting casts were assembled (Plate i). Once assembled the upper member was released via the locking screws. The numbers on the casts used were carefully noted and recorded.

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[c]Great Lakes Orthodontics, Tonawanda, NY, USA. 14150-5890

Plate i. In Vitro testing Apparatus

The load cell was laid horizontally on the lab bench and the zero axis set. It was then hung from a fixed point and the left axis set for 400 grams. The upper member of the articulator was released to allow free movement and its weight determined by hanging it from the measuring device. A 500 and 1000 gram weight was then placed on the front portion of the upper member. The standard deviation of the testing apparatus and measurement technique, as determined from a static load calibration run using known weights of 300, 500, 700, and 1000 grams, equalled 0.82 grams. Care was taken to match results from identical pairs of mounting casts to eliminate variance due to the amount of plaster. See Appendix C for in vitro test data.

The determination of μ was made using teeth set up in plaster on a SAM articulator. Known forces were applied through the dental contact surfaces which had been separated by a stainless steel strip. The strip was withdrawn and the force required for withdrawal recorded on the strip chart recorder. In this way the IPF was measured and f values were determined using the equation:

$$IPF = f/2\mu$$

$$\mu = f/2(IPF)$$

Using the extracted teeth, the mean value of μ was found to be 0.145 (S.D. = 0.002). See Appendix D for test data.

c. Data Collection

The test protocol for measuring f values with the designed instrumentation was as follows:

A suitable subject was selected; in good health, healthy dentition with healthy periodontal tissues. As determined from a brief clinical examination and history no sign or symptom of temporomandibular joint dysfunction was present in any of the subjects.

See Plate ii for a photograph of the testing apparatus in the mouth.

Plate ii. Photo of testing apparatus in mouth

The test procedure was as follows:

1. The subject relaxed in an upright position in a dental chair. The conditioner and recorder were turned on. The pen tip of the recorder was engaged and instrumentation calibrated.

2. The mesial contact point of the first molar in the quadrant to be tested was thoroughly flossed with unwaxed dental floss, isolated with cotton rolls and then air dried. The strip chart recorder paper rotating mechanism was activated.

3. The .015 inch metal strip was placed (with a gentle rocking motion) in the contact point to be tested. The end with the hole was placed to the buccal extending approximately 2 to 3 mm from the contact point.

4. In 2 to 3 seconds the measuring apparatus was attached via the fish hook to the hole in the metal strip.

5. Starting after the initial strip placement approximately five continuous seconds were allowed to elapse. A pulling force was then gradually applied to the ring of the load cell and the reading noted at which strip movement just began. Just after the point of initial strip movement the pulling force was relaxed for approximately 1 second and then reapplied.

The value peak of the spike recorded was noted for subsequent IPF computation. See Figure 4 for a sample strip chart recording.

6. Each subject was quickly tested three times per contact

point to ensure reproducible results. The IPF used was the average of the three recorded. A new strip was used for each set of contact point measurements.

All test information was stored on the strip chart recorder graph paper. It was immediately labelled with the subjects name, date, time and reference number.

Using the formula IPF = $f/2\mu$ IPF's were calculated for each quadrant tested.

Sample of Strip Chart Recording

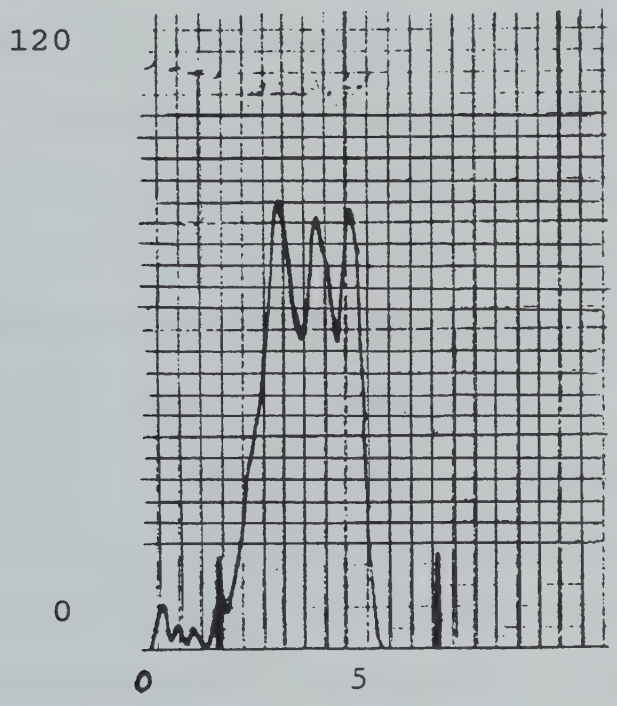

Figure 4. The recorder was turned on and the pulling force applied 5 seconds after strip placement. The first long vertical recording represents the initial force application. The spike represents the moment of initial strip motion. The motion was repeated three times giving three spikes. The tip of the spike equals the f value recorded.

d. Statistical Methods

The raw data was gathered together and summarized using common descriptive statistics that include frequency distribution tables, means, standard deviations, and ranges.

Inferential statistical analysis methods used include Student's t tests, the calculation of product moment correlation coefficients, and multiple linear regression.

The data was analyzed by the author and two statisticians working independently of each other. The first statistician is a full time faculty member of the Department of Computing Systems, University of Alberta. The second statistician analyzed the data as a case analysis project in partial fulfilment of the requirements for the degree of Master of Science, Department of Statistics and Applied Probability, University of Alberta. The approach taken varied slightly between the two. The services of the consultants were used for the more complex and lengthy mathematical computations of, for example, the multiple regression analysis. The author also performed the simpler calculations of standard deviations and paired Student's t tests.

i. **Descriptive Statistics**

The sample studied is best defined as a sample of convenience. The subjects represented consecutive patients referred to the participating oral surgeons office that met the selection criteria of the study. Of the 105 subjects initially accepted into the study only 29 finished the

required set of 4 measurements. The sample may reflect the specific referral patterns unique to the oral surgeons office used. Care should be taken in extrapolating conclusions from this sample to the general population. For example, the percentage of the sample that had a history of orthodontic treatment is probably unique to this sample and not applicable to the population as a whole.

The frequency distribution tables used are based on a standard format commonly used in the orthodontic literature. The class intervals used were selected on the basis of presenting the essential features of the data in a clear way. They have been labelled and captioned to facilitate easier use by the reader.

The arithmetic means were calculated using commonly accepted mathematical practices.

Measures of variability of the data collected include the standard deviation, and its square, the variance. The variance was calculated using:

$$\text{Variance} = s^2 = \Sigma(X - \bar{X})^2/(n - 1)$$

ii. **Inferential Statistics**

One sided, upper level Student's t tests were used to test for significant differences between the means of right and left IPFs for the test times, for significant differences between the means of T_1 and T_2 or T_3 and T_4, and for significant

differences between the mean presurgical IPF and the mean postsurgical IPF. The data was analyzed using a standard software package (The SAS System[d]). The tests were one sided as, based on reported findings in the literature[22,23,31] and the second pilot study reported, it seemed highly unlikely that removal of the mandibular third molars would be associated with an increased resting IPF. The null hypothesis was rejected at $P<0.05$.

The magnitude of the linear relationships between the dependent variable and the independent variables were calculated using sample product moment correlation coefficients (there is no assumption of a causal effect of one variable on the other). The data was analyzed using a standard software package (SPSS-X Release 3.0 for IBM MTS[e]). From these, population product moment correlation coefficients (called Pearson's Correlation Coefficients after Karl Pearson) were estimated.

In the interest of thoroughly analysing the data two approaches were used and the results reported. In the first, the combined left and right mean difference between the pre and postsurgical resting IPF was correlated with the independent variables. The combined mean difference (the

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[d] SAS Institute, Inc. SAS user's guide: basics, version 5 edition. Cary, N.C.:SAS Institute, 1985.

[e] SPSS Inc., 444 North Michigan Ave., Chicago, Illinois. 60611

dependent variable) is labelled as Y and referred to as cdiff in Table 12. In the second, the mean differences between the pre and postsurgical resting IPF were separated for right and left and then individually correlated with the independent variables. The left and right mean differences are referred to as rdiff and ldiff in Appendix F. Significance was denoted at $P<0.05$.

Multiple regression analysis is concerned with providing a mathematical model of the linear relationship between a dependent variable and the independent or predictor variables. The mean level of a dependent variable may be predicted for a set of values for the independent variables.

The multiple regression analysis of the data in this thesis was analyzed with a standard software package (SPSS-X Release 3.0 for IBM MTS [(c)]) based on multiple regression analysis. The assumptions of this analysis include linearity, independence (Y or independent variable observations are independent of each other), existence, and normality of the dependent variable. For a given set of independent variables, Y is a random variable with a certain probability distribution that has a finite mean and variance.

The model used was based on the best estimate of the multiple regression equation. Two models were tested and the one selected (based on goodness of fit measured by the coefficient

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[(c)] SPSS Inc. 444 North Michigan Ave. Chicago, Illinois. 60611

of determination or R^2 value where R is a measure of the correlation between the dependent variable and the joint set of independent variables in the model) used Y^2 to produce a better fit.

$R^2 = \frac{(SSY - SSE)}{SSY}$ is a quantitative measure of how well the fitted model predicts the dependent variable. It varies from 0-1 with 1 indicating a perfect fit.

The regression model used was tested for significance using a F-test. To perform the test use was made of mean square quantities. The F test examines the

$$F = \frac{\text{MS Regression}}{\text{MS Residual}} = \frac{SSY - SSE/k}{SSE/(n-k-1)}$$

where k = number of independent variables

SSE = sum of squares of prediction error

SSY = sum of squares of Y observations

significance of the entire set of variables to predict the value of Y. The model was found to be significant at F = 6.23 or P = 0.0001 (indicating a significant linear relationship between cdiff and the independent variables).

Chapter 4

RESULTS

a. Introduction

The force recordings were taken between the mandibular first molar and its most mesial proximal neighbour. These were determined approximately one month prior (T_1), immediately prior (T_2), one month following (T_3), and then again two months subsequent (T_4) to removal of the mandibular third molars. From these force recordings left and right IPF's were calculated for each time and used in data analysis. Of the 105 initial participants, 29 completed the series of 4 measurements required in the study.

Two initial pilot studies were performed. The first was done to determine physiologic variation in resting IPF as measured between the mandibular first molar and its most mesial proximal neighbour. The second pilot study was undertaken to test the research questions on a preliminary basis.

b. Pilot Studies

An initial pilot study was performed to determine physiologic variation in resting IPF as measured between the mandibular first molar and its most mesial proximal neighbour. The subjects were tested on three consecutive days, left 2 days and then tested on three more consecutive days. Test results indicate one standard deviation of individual physiologic IPF variation to be equal to approximately 5% to 10% of the

individual's mean resting IPF. The data of this study are listed in Table 2 following.

Physiologic IPF Variation Pilot Study

IPF Values (grams)

Subject	Right	Left	Day
NW	841.4	287.4	1
	913.8	305.7	2
	885.1	275.8	3
	797.7	289.7	6
	888.5	302.3	7
	892.0	306.9	8
Mean-	869.8	- 296.6	
S.D.-	42.5	- 12.4	
DT	1356.3	451.7	1
	1326.4	491.9	2
	1372.4	510.3	3
	1241.4	544.8	6
	1245.6	429.9	7
	1308.6	531.7	8
Mean-	1308.5	- 493.4	
S.D.-	55.0	- 45.1	

Table 2. Results of pilot study to determine physiologic variation in IPF. Subjects were tested on the days as listed. Means and standard deviations are given. The contact point of the mandibular first molar and second bicuspid was tested.

Physiologic IPF Variation Pilot Study (continued)

	IPF Values (grams)		
Subject	Right	Left	Day
MB	1093.1	1048.3	1
	948.3	890.5	2
	1014.9	985.1	3
	1180.5	898.2	6
	971.3	990.8	7
	1114.8	892.0	8
Mean -	1058.8	- 950.8	
S.D. -	95.1	- 66.6	
JP	1097.7	1902.3	1
	1086.2	1734.5	2
	1354.0	1873.6	3
	997.7	1686.2	6
	1062.1	1796.6	7
	1044.8	1667.8	8
Mean -	1107.8	- 1776.8	
S.D. -	126.0	- 97.6	

Table 2 (con't). Results of pilot study to determine physiologic variation in IPF. Subjects were tested on the days as listed. Means and standard deviations are given. The contact point of the mandibular first molar and second bicuspid was tested.

A second pilot study was undertaken to test the research questions on a preliminary basis. The resting IPF of three individuals was determined approximately 1 hour prior to the removal of their mandibular third molars and again 9 to 10 days later. The contact point of the mandibular first molar and second bicuspid was measured. Results indicated reductions in resting IPF ranging from 26% to 77%. No case demonstrating an increase in resting IPF was noted. Test results are listed in Table 3 following.

Second Pilot Study

IPF Values (grams)

Subject	Right	Left	Date
S.W.	890.8	656.3	12/2/91
	320.7	485.1	21/2/91
J.F.	579.3	879.3	12/2/91
	320.7	485.1	21/2/91
T.B.	782.8	663.2	12/2/91
	175.9	455.2	22/2/91

Table 3. In this second pilot study resting IPFs were determined approximately 1 hour prior to removal of the left and right mandibular third molars and again 9 to 10 days later. Reduction in resting IPFs ranged from 26% to 77% of the original IPF calculated.

c. Main Study Results

The resting interproximal contact force was calculated for each individual in the mandibular left and/or right quadrants for T_1, T_2, T_3, and T_4 (Appendix E). The mean, standard error, range, and standard deviation of the IPF for each time is listed in Table 4. A zero value indicates a contact point open more than the thickness of the stainless steel measuring strip. The data is presented in graphic form in Figure 5. Inferential statistical analysis follows.

Calculated Resting IPF Values (grams)

	T_1R	T_1L	T_2R	T_2L
Mean	678.2	568.7	668.4	578.8
St. Dev.	661.6	363.8	632.3	363.8
Minimum	93.1	13.8	55.2	18.3
Maximum	3678.2	1593.0	3459.1	1464.4
S.E.	122.8	68.7	117.4	68.8

	T_3R	T_3L	T_4R	T_4L
Mean	427.8	358.9	456.2	363.1
St. Dev.	525.1	282.0	475.8	223.5
Minimum	0.0	0.0	0.0	0.0
Maximum	2706.9	947.1	2620.7	994.2
S.E.	97.5	53.3	88.4	42.2

Table 4. Descriptive statistics for resting IPF values calculated over the study period (mean, standard deviation, standard error, and range). Values were determined for right and left mandibular quadrants approximately 1 month prior (T_1), immediately prior (T_2), one month after (T_3), and then again 2 months (T_4) after removal of the mandibular third molar. The contact point chosen for measurement was between the mandibular first molar and its mesial proximal neighbour. The values were calculated using $IPF=f/2\mu$ where $\mu=0.145$ and f equalled the force measured on strip withdrawal. Zero indicates an open contact point.

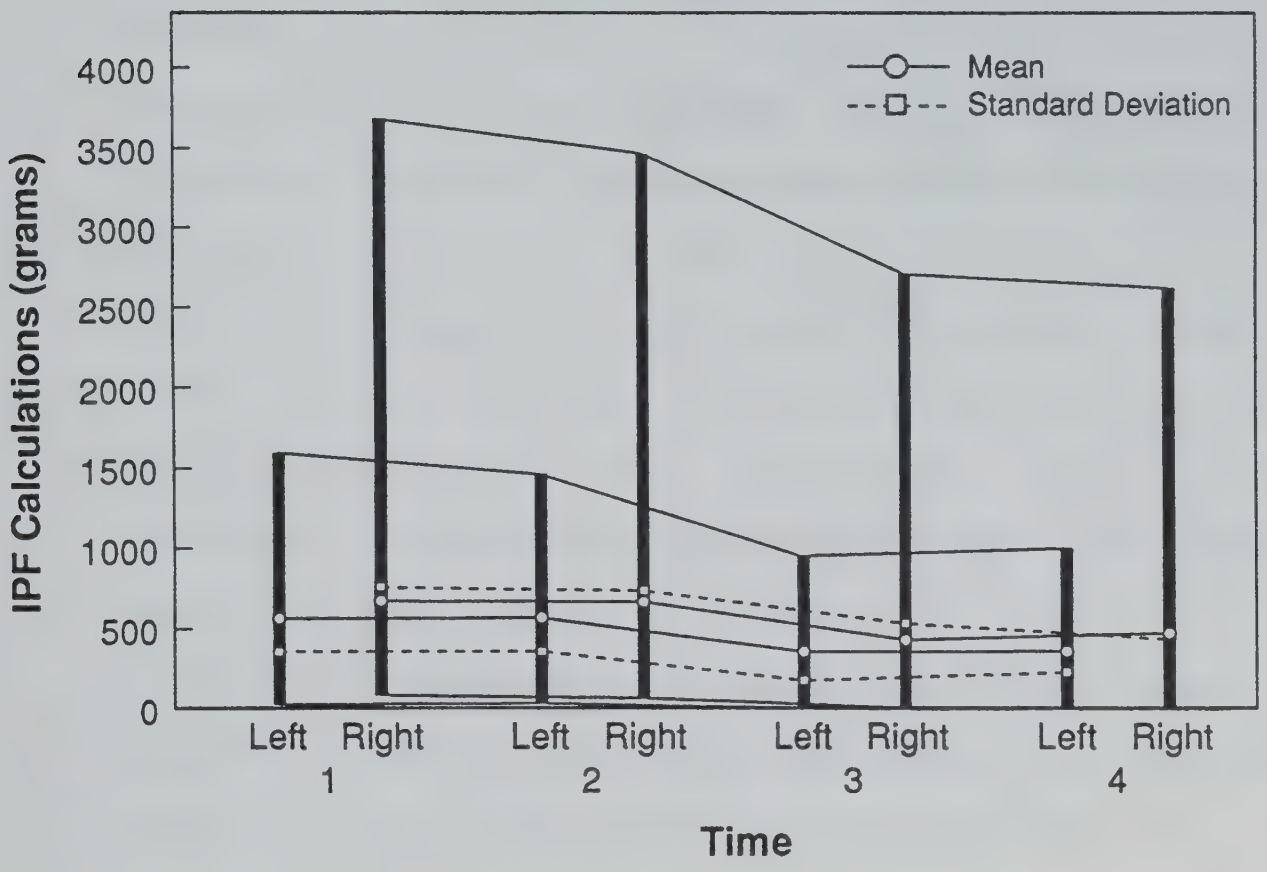

Figure 5. Graphic presentation of the data in Table 4. The mean, standard deviation and range are shown for each quadrant at each time. One sided, upper level Student's t tests indicated the differences between left and right for each time were not statistically significant.

One sided, upper level Student's t tests were calculated comparing right and left for each time and no significant difference was found between the right and left for each time. See Table 5 for the individual t and P values calculated for each time. For subsequent calculations right and left were combined.

Analysis of variance comparing right to left for the test times also indicated no significant difference between right and left (P = 0.51, F = 0.45).

T_1 was then compared to T_2 using a one sided, upper level Student's t test. No significant difference was noted between these two preoperative time periods (t = 0.27, P = 0.391).

Analysis of variance also indicated no significant difference between the two times (P = 0.9778 and F = 0.00).

T_3 was then compared to T_4 using a one sided, upper level Student's t test. No significant difference was noted between these two postoperative time periods (t = 0.56, P = 0.296).

Analysis of variance also indicated no significant diefference between the two test periods (P = 0.41228, F = 0.70).

The dependent or outcome variable was the difference between the resting presurgical IPF and the resting postsurgical IPF and computed as follows:

$$\frac{T_1 + T_2}{2} - \frac{T_3 + T_4}{2}$$

The mean presurgical IPF was 624.23 grams and the mean

postsurgical IPF was 402.2 grams. The mean difference was 222.03 grams.

The difference between the mean presurgical resting IPF and the mean postsurgical resting IPF was tested for significance using a one sided, upper level Student's t test. The mean presurgical IPF was determined to be significantly different from the mean postsurgical resting IPF ($t = 5.75$, $P = 0.000$). Analysis of variance also confirmed this finding ($F = 10.01$, $P = 0.00394$).

See Tables 5 and 6 for a summary of t test and analysis of variance results.

t - Test Table

Test	(difference) Mean	Standard Deviation	T Value	1-Tail Probability
R_1 vs L_1	107.0679	437.939	1.29	0.104
R_2 vs L_2	96.8857	439.811	1.17	0.127
R_3 vs L_3	69.1100	389.670	0.94	0.178
R_4 vs L_4	94.6857	383.471	1.31	0.101
T_1 vs T_2	4.2696	84.687	0.27	0.396
T_3 vs T_4	16.9750	161.153	0.56	0.296
T_{1+2} vs T_{3+4}	222.4741	204.721	5.75	0.000*

Table 5. Summary of t-test results showing mean differences, standard deviations, t values and P values for comparisons made. The Null Hypothesis was rejected at $P<0.05$. * denotes significance at $P<0.05$.

Analysis of Variance Table

Test	F-Ratio	Probability
Right vs Left	0.45	0.50743
T_1 vs T_2	0.00	0.97781
T_3 vs T_4	0.70	0.41228
(T_{1+2}) vs (T_{3+4})	10.01	0.00394

Table 6. Summary table of F ratios and probability values determined for the tests mentioned.

Student's t-tests are a test of one group to another. Analysis of variance looks at several means (i.e. tests several groups at once) at the same time taking into account error term for each variable. Student's t-tests use a residual for error term. As a result the t-test P values will differ from analysis of variance P values for similar tests.

The independent variables examined were age, gender, angle of impaction, depth of impaction, stage of root development, a history of orthodontic treatment, and missing teeth. Frequency distribution tables for angle of impaction, depth of impaction, stage of root development, history of orthodontic treatment, and missing teeth are listed in Tables 7 - 11.

Angle of Impaction Data

Angle of Impaction (degrees)	Frequency	Percent
0 - 17	3	5.3
18 - 35	10	17.5
36 - 53	19	33.3
54 - 71	15	26.4
72 - 89	10	17.5
TOTAL	57	100.0
MEAN 50.9	STD ERR 3.6	STD DEV 19.3

Table 7. The angle of impaction was determined by first drawing a "best fit" line through the long axis of the mandibular third molar. The distal aspect of the angle formed by this line and the occlusal plane was measured as the angle of impaction. The more horizontal the mandibular third molar the lower the angle reported. Reported descriptive statistics: Mean - 50.9, S.D. - 19.3, S.E. - 3.6.

The angle of impaction table indicates that all third molars studied were mesioangular impactions. Approximately 5% tended towards being horizontal impactions. Approximately 18% tended towards being vertically upright teeth.

Stage of Root Development

Stage of Root Development (Nolla Value)	Frequency	Percent
6	2	3.5
7	9	15.8
8	19	33.3
9	27	47.4
TOTAL	57	100.0

MEAN 8.25 STD ERR 0.16 STD DEV 0.86

Table 8. The stage of root development was determined according to Nolla[46]. The radiographic appearance of the mandibular third molar was compared to drawings and each tooth was given a developmental score according to the drawing that it most nearly approximated. If less than one third of the root had completed formation the tooth was labelled a 6, if one third of the root had completed formation the tooth was labelled a 7, if two thirds of the root was completed the tooth was labelled an 8, and if the root had almost completed formation but still had an open apex it was labelled a 9. Reported descriptive statistics: Mean - 8.25, S.D. - 0.86, S.E. - 0.16.

The Nolla Table indicates that all third molars studied had initiated root formation but none had completed root

formation. 97% had one third or more of root formation complete.

Depth of Impaction

Depth of Impaction(mm)	Frequency	Percent
0 - 3	14	24.6
4 - 7	18	31.6
8 - 11	22	38.5
12 - 15	3	5.3
TOTAL	57	100.0

MEAN 6.63 STD ERR 0.65 STD 3.45

Table 9. The depth of impaction was measured (mm) as the distance between the most occlusal portion of any part of the mandibular third molar and the occlusal plane. This was measured along a line perpendicular to the mandibular occlusal plane. Reported descriptive statistics: Mean - 6.63, S.D. - 3.45, S.E. - 0.65.

The Depth of Impaction Table indicates a relatively even distribution of mandibular third molars in 3 of the 4 class intervals described. The deepest impaction class interval contained approximately 5% of the sample.

History of Orthodontic Treatment

Hx of Ortho	Frequency	Percent
Yes	18	62.1
No	11	37.9
TOTAL	29	100.0

Table 10. At the initial screening visit the participants were asked by the investigator as to whether or not they had a history of orthodontic treatment. The answer was recorded in their file.

As can be seen from the table approximately 62% of the sample had a history of orthodontic treatment.

Missing Teeth Data

Missing Teeth (# of)	Frequency	Percent
0	20	69.0
1	3	10.3
2	6	20.7
TOTAL	29	100.0

Table 11. The number of missing teeth (excluding the third molars) was tabulated for each subjects mandibular dental arch. This discrete data was scored from 0-2 missing teeth.

69% of the sample had intact mandibular dental arches (excluding the third molars). The teeth missing were either single incisors or bicuspid teeth.

The magnitude of the linear relationships between the dependent variable and the independent variables were calculated using standard sample product moment correlation coefficients. The formula:

$$r = \frac{\Sigma xy - n\bar{x}\bar{y}}{(n-1)S_xS_y}$$

was used where S_x, S_y are the sample standard deviations and $\bar{x}$, $\bar{y}$ are the sample means of the n x's and y's respectively. Two approaches were used and the results reported.

In the first approach the combined left and right mean difference between the pre and postsurgical resting IPF was correlated with the independent variables. The combined mean difference is labelled as Y (the dependent variable) and referred to as cdiff in Table 12. In the second (Table 13), the mean differences between the presurgical and postsurgical resting IPFs were separated for right and left and then individually correlated with the independent variables. The left and right mean differences are the dependent variables and referred to as rdiff and ldiff in Appendix F. Significance was denoted at $P<0.05$.

A partial tabulation of the correlation coefficients is listed in Tables 12 and 13. Complete correlation coefficient data for rdiff and ldiff is listed in Appendix F.

Correlation Coefficient Table

(Y = dependent variable = cdiff)

Value	Age	Gender	Nolla Value	Depth	Hx Ortho Tx	Missing 2 Teeth	Angle
r	.387	.057	.103	.278	-.280	-.270	-.205
P	.003*	.672	.444	.037*	.035*	.042*	.127

Table 12. The dependent variable cdiff was correlated with the independent variables listed. These are as previously defined: depth is the depth of impaction of the third molar, angle is the angle of impaction of the third molar, Hx Ortho Tx is a positive history of orthodontic treatment. Correlation coefficients (r values) are listed. Correlations significant at $P<0.05$ are indicated by *.

Significant but weak correlations were found between cdiff and age ($P = 0.003$, $r = 0.387$), cdiff and depth ($p = 0.037$, $r = 0.278$), cdiff and a previous history of orthodontic treatment ($p = 0.035$, $r = -0.280$), and cdiff and two missing teeth ($p = 0.042$, $r = -0.270$). Positive change in cdiff was associated with a statistically significant linear positive (increase) change in the age of the subject or depth of impaction. A history of orthodontic treatment or two missing teeth in the arch was associated with a statistically significant linear negative (decrease) change in cdiff.

Correlation Coefficient Table

(Y = dependent variable: Y = rdiff and Y = ldiff)

	ldiff	rdiff
Age	0.3234	0.3878
	P=.047*	P=.019*
LAngle	-.2619	-
	P=.089	-
RAngle	-	-.1544
	-	P=.212
LNolla	0.0860	-
	P=.332	-
RNolla	-	0.1199
	-	P=.268
LDepth	0.4318	-
	P=.001*	-
RDepth	-	0.1319
	-	P=0.248
Orthox	-0.2715	-0.2877
	P=0.081	P=0.065
Ifmiss	-0.3377	-0.3378
	P=.039*	P=.037*
Gender	-0.0466	-0.0684
	P=0.407	P=0.362

Table 13. Correlation coefficients and P values with right and left treated separately. * denotes significance at P<0.05. Independent variables are as previously defined. If missing

refers to the absence of 2 missing teeth.

The data in Table 13 shows similar correlation coefficient values and levels of significance as to Table 11. Note that there was a significant positive linear relationship between depth of impaction and the mean difference between pre and postsurgical resting IPF on the left side only. History of orthodontic treatment correlation coefficient values are no longer significant. Ifmiss refers to the absence of 2 missing teeth.

Three surgeons (K, S, and T) participated in this study . See Table 14 for a frequency distribution table of treatment by the surgeons. Because of the small number of cases treated by Dr. K (n=2) he was not included in any of the statistical analysis. Data analysis indicated that rdiff was not significantly related to the surgeon (F=0.77, P=0.507).

Surgeon Data

Surgeon	Frequency	Percent
K	2	6.9
S	18	62.1
T	9	31.0
TOTAL	29	100.0

Table 14. A listing of the number of operations performed by each of the three surgeons in the study. Surgeon K was not

included in any of the statistical analysis.

Other significant correlations were noted on data analysis. It should be noted that the correlation coefficient is only a measure of the degree of linear relationship in a two variable population, and not a measure of any other relationship. Nolla was positively correlated with age (Right-r=.4030 P=.015; Left-r=.4028 P=.017) indicating that as age progressed so did the stage of root development. Orthodontic treatment was positively correlated with missing teeth at r=.5509 and P=.001 (not unusual as extractions are commonly performed as part of orthodontic treatment). Significant and expected negative correlations were noted between langle/ldepth (r=-.4979 P=.004)and rangle/rdepth (r=-.6132 P=.000) indicating that as the angle of impaction decreased the depth of impaction increased. A significant negative correlation was noted between age and a history of orthodontic treatment indicating that as age increased a history of orthodontic treament decreased (r=-.4328 P=.010).

Multiple regression analysis of dependent variable cdiff and the independent variables using the SAS system resulted in an R^2 of 0.471. This indicated that approximately 47% of rdiff variation could be explained by the independent variables.

Using forward selection stepwise regression the independent variables were analyzed on the basis of the amount of variation they explained of rdiff. With age as the only variable in the equation an R^2 value of 0.162 was computed at

F = 5.012 or P = 0.034. Thus the higher the age the higher the rdiff with age explaining approximately 16% of the variation in rdiff. Analysis of the other independent variables indicated no other statistically significant relationships.

Using forward selection stepwise regression the independent variables were also analyzed on the basis of the amount of variation they explained of ldiff. With depth as the only variable in the equation an R^2 of 0.187 was computed at F = 5.960 or P = .022. Thus the greater the depth of impaction the larger the ldiff with depth explaining approximately 19% of the variation in ldiff. No other significant relationships were noted in the multiple regression analysis.

Chapter 5

DISCUSSION

The results show that during the three month test period there was a significant decrease in the resting IPF associated with the removal of developing/erupting mandibular third molars. The mean difference reported was 222.03 grams with the standard error of the mean being 41.96 grams. No significant change in the IPF was noted during the preoperative or two month postoperative period.

These findings tend to support the theory that the removal of developing/erupting mandibular third molars is associated with a release of pressure from the back of the arch. This may implicate them as a possible causative agent in the development of late mandibular anterior crowding. The association of the removal of mandibular third molars with a significant decrease in resting interproximal contact force has implications.

Southward et al[40] have reported on the mandibular anterior component of occlusal force associated with the unilateral loading of second molars by comparing IPF's before and after occlusal loading of the posterior teeth. Using a similar measurement technique they confirmed the existence of an anterior component of occlusal force and found that it exhibited an exponential decay as it dissipated anteriorly

through the mandibular dental contact points. Using the reported rdiff, force decay calculations at each mesial contact point would indicate that the mandibular third molars could be associated with a mesial force or pressure from behind of 50 grams operating between the cuspid and lateral in a first bicuspid extraction case and a mesial force of 25 grams at the distal of the central incisor.

Weinstein[47,48] has reported that forces of such low values as 1.68 grams, if acting over a sufficient period of time, are capable of moving teeth. The reported mesial force that may be generated by a developing/erupting mandibular third molar is well within the range associated with tooth movement.

Although the present findings do not provide conclusive evidence that mandibular developing/erupting third molars generate a mesial force or pressure from behind, their removal is associated with a significant decrease in resting interproximal contact force. Differentiating the effect of the surgical procedure from the effect of removing the tooth would be difficult. Performing a mock surgical procedure in mandibular quadrants congenitally missing their third molars while measuring associated IPF changes would help in analysis of this problem.

Multiple regression analysis of the dependent variable (rdiff) and the independent variables gave a R^2 of 0.4708 indicating that the independent variables studied could only explain about 50% of the variation in rdiff.

The rdiff may also be due to a distal settling of the occlusion with a concomitant relaxation of interproximal contact forces.

In a preliminary study, Richardson[49] found distal movement of the lower first molar and reduced anterior crowding following lower second molar extraction. In the absence of mandibular second molar extraction no distal drift of the first molar has been reported[32]. Schwarze[39] found similar changes in development of crowding in response to removal of mandibular third molars. As positional changes of the mandibular second molar were not monitored radiographically in this study it is not possible to quantitatively evaluate distal settling. Tissue contracture associated with the healing of the surgical site, acting through the transeptal fiber network, represents a possible mechanism of action.

While it is difficult to accurately measure the forces generated by human tooth eruption, the eruption of teeth is certainly a net result of predominantly occlusally directed forces, whatever the theoretical origin[50]. The eruptive force associated with the mandibular third molar is not reported in the literature. The rdiff reported could reflect the eruptive force change associated with the removal of the mandibular third molar. The eruptive associated with rat incisors has been reported to be in the range of 5 grams(51). The magnitude of the eruptive force associated with the human mandibular third is likely equally small.

Investigators(6,52) have also attributed the occurrence of late mandibular anterior crowding to incisor uprighting seen as part of growth and development changes in the maturing teenager. Richardson[31] however, noticed on average that the lower incisors tended to procline and move forward over the five year period she studied. This movement was associated with increased incisor crowding and mesial first molar movement. The differences are most likely attributable to the choice of reference planes from which incisor angulation was measured (Bjork used SN and Richardson used the mandibular plane). Mandibular plane measurements would not take into account external mandibular growth rotation patterns. Radiographic positional changes of the lower incisors and growth rotation were also not monitored as part of this study. Proclining and anteriorly repositioning lower incisors are positional changes consistent with mandibular wisdom teeth exerting a pressure on the back of the dental arch.

The physiological factors that affect interproximal contact point tightness are only now being investigated. The variation of proximal tooth contact tightness body postural change has been described by Southard et al[43]. For the present study patient positioning was standardized by the use of an automatic return dental chair. All measurements were taken on the return position with the head resting in the doughnut headrest.

The resistance to withdrawal of the strip is also a function

of the properties of the individual's periodontal ligament. These properties may vary with time and with the periodontal condition of each tooth.

Parafunctional habits (clenching or bruxing) have been associated with an increased anterior component of force[40]. The presurgical patients presenting to be tested would probably be in a heightened emotional state as to the postsurgical patients. The presurgical patients could be more likely to have bruxed or clenched prior to their measurement appointment. Their resting IPF scores may have been higher due to presurgical parafunctional clenching or bruxing.

The measurement technique itself represents a major limitation of this study. The width of a normal periodontal ligament ranges from 0.12 to 0.38 inches. The introduction of the 0.015 inch thickness stainless steel strip into the contact point being measured would alter the dental system being investigated. The resistance to withdrawal would vary with the thickness of the strip used. The thinner the strip used to measure, the closer the measurement would reflect the true resting IPF. The shim stock used was the thinnest, readily available that would not tear with use. Preliminary experiments by Southard al[43] did indicate that measured contact tightness did decrease with thinner strips. If a thinner measuring strip was employed in this study (providing it met clinical requirements), the rdiffs reported could have decreased in value.

In the pilot study to determine physiologic variation in resting IPF and in the main sample studied the mean of right side calculated IPF's was greater than the mean of the left side calculated IPF's. This difference was 16% and 19% respectively (in the second pilot study mentioned the IPF's calculated on the left side were on average 15% greater than the right side averages). These differences, although not statistically significant, could be due to several factors.

Measurement technique is a possible responsible factor. The instrumentation was located on opposite sides of the subject being measured in the two studies mentioned.

The differences may also be attributable to right sided versus left sided chewing patterns. Either pattern could potentially result in an increased anterior component of occlusal force on that particular side. This could result in tighter interproximal contact points on the affected side.

Chapter 6

CONCLUSIONS

1. There is a significant reduction in resting IPF associated with the surgical removal of mandibular developing/erupting third molars.

2. The change in resting IPF associated with the surgical removal of mandibular developing/erupting third molars is not significantly related to the gender of the individual but is significantly related to ($p=.003$) the age of the individual. The older the individual the larger the reported change in IPF.

3. The change in resting IPF associated with the surgical removal of mandibular developing/erupting third molars is significantly related to but weakly correlated with the depth of impaction. The deeper the impaction the larger the reported change in IPF. It is not significantly related to the angle of impaction or stage of root formation.

4. The change in resting IPF associated with the surgical removal of developing/erupting mandibular third molars is not significantly related to a previous history of orthodontic treatment or any additional missing teeth.

5. The resting IPF does not vary significantly in a dentally unchanged individual over a two month period of time.

6. The resting IPF does not vary significantly in the two

months following the surgical removal of mandibular developing/erupting third molars.

7. The change in resting IPF associated with the surgical removal of developing/erupting wisdom teeth is not significantly related to the surgeon.

Suggestions for further study:

1. Concomitant radiographic implant study to investigate positional changes of the mandibular second molar occurring during the period of investigation.

2. Longer term follow up of the individuals studied to investigate the permanence of the IPF change noted.

3. Studies to determine the effect of changes in blood pressure on resting IPF.

BIBLIOGRAPHY

1. Baume, L.R.: Physiological tooth migration and its significance for the development of occlusion. J. Dent. Res. 29:12-132; 331-337; 338-348, 1950.
2. Brown, V.P. and Daugaard-Jensen, I.: Changes in the dentition from the early teens to the early twenties. Acta Odonto. Scand. 9:177-192, 1950-1951.
3. De Kock, W.H.: Dental arch depth and width studied longitudinally from 12 years of age to adulthood. Am. J. Orthod. 62:56-66, 1972.
4. Knott, V.B.: Size and form of the dental arches in children with good occlusion studied longitudinally from age 9 to late adolescence. Am. J. Phys. Anthrop. 19:263-284, 1961.
5. Vego, L.: A longitudinal study of mandibular arch perimeter. Angle Orthodont. 32: 187-192, 1962.
6. Bjork, A. and Skieller V. Facial development and tooth eruption. An implant study at the age of puberty. Am. J. Orthodont. 62: 339-383, 1972.
7. Begg, P.R.: Stone age man's dentition with reference to anatomically correct occlusion, the etiology of malocclusion, and a technique for its treatment. Am. J. Orthodont. 40:298-312, 1954.
8. Lammie, G.A. and Posselt, U.:Progressive changes in

the dentition of adults. J. Periodont. 36: 443-454, 1965.

9. Trauner, F.: Causes of progressive movements of the teeth toward the front. American Orthodontist, January 1912.

10. Moss, J.P. and Picton, D.C.: Mesial drift of teeth in adult monkeys when forces from the cheeks and tongues have been eliminated. Arch. Oral Biol. 15: 979-984, 1970.

11. Stallard, H.: The anterior component of the force of mastication and its significance to the dental apparatus. The Dental Cosmos. 5:457-474, 1923.

12. Picton, D.C. and Moss J.P.: The part played by the trans-septal fibre system in experimental approximal drift of the cheek teeth of monkeys (Macaca Irus). Arch. Oral Biol. 18: 669-680, 1973.

13. Moss J.P. and Picton D.C.: The effect on approximal drift of cheek teeth of dividing mandibular molars of adult monkeys. Arch. Oral Biol. 19:1211-1214, 1974.

14. Moss J.P. and Picton D.C.: Experimental mesial drift in adult monkeys (Macaca Irus). Arch. Oral Biol. 12:1313-1320, 1967.

15. Weinman, J.P. and Sicher, H.: Bone and bones. The C. V. Mosby Company, St. Louis, 1947.

16. Picton, D.C. and Moss J.P.: The effect on approximal drift of altering the horizontal component of biting

force in adult monkeys (Macaca Irus). Arch. Oral Biol. 25:45-48, 1980.

17. Yilmaz, R.S., Darling, A.I., and Levers B.G.H.: Mesial drift of human teeth assessed from ankylosed deciduous molars. Arch. Oral Biol. 25:127-131, 1980.

18. Waldron, R.: The influence of erupting and impacted third molars on the occlusion of treated cases. Int. J. Orthod. 23:221-234, 1937.

19. Waldron, R.: Reviewing the problem of retention. Am. J. Orthod. Oral Surg. 28:770-791, 1942.

20. Richardson, M. E.: The role of the third molar in the cause of late lower arch crowding: A review. Am. J. Orthod. Dentofac. Orthop. 95:79-83, 1989.

21. Andrews, L.A.: The six keys to normal occlusion. Am. J. Orthod. 62:296-309, 1972.

22. Schwarze, C. W.: The influence of third molar germectomy-a comparative long term study. Trans. Third Intl. Ortho. Cong. 551-562, 1975.

23. Southard, E. S. et al.: Mesial force from unerupted third molars. Am. J. Orthod. Dentofac. Orthop. 99:220-225, 1991.

24. Broadbent, B.H.: The influence of the third molars the alignment of the teeth. Am. J. Orthod. Oral Surg. 29:312-330, 1943.

25. Vego, L.: A longitudinal study of mandibular arch perimeter. The Angle Orthodontist. 32:187-192, 1962.

26. Lundstrom, A.: An investigation of 202 pairs of twins regarding fundamental factors in the etiology of malocclusion. Dent. Rec. 69:251-264, 1949.

27. Forsberg, C. M.: Tooth size, spacing, and crowding in relation to eruption or impaction of third molars. Am. J. Orthod. Dentofac. Orthop. 94:57-62, 1988.

28. Bergstrom, K. and Jensen, R.:The significance of the third molars in the aetiology of crowding. A biometric study of unilateral aplasia of the third molars. Trans. Eur. Ortho. Soc. 84-96, 1960.

29. Keene, H. J.: Third molar agenesis, spacing and crowding of teeth, and tooth size in caries resistant naval recruits. Am. J. Orthod. 50:445-451, 1964.

30. Richardson, M. E.: Late lower arch crowding: facial growth or forward drift. E.J.O. 1:219-225, 1979.

31. Richardson, M. E.: The effect of lower second molar extraction on late lower arch crowding. Angle Orthod. 53:25-28, 1983.

32. Richardson, M. E.: Lower molar crowding in the permanent dentition. Angle Orthod. 55:51-57, 1985.

33. Richardson, M. E.: Late lower arch crowding: the role of facial morphology. Angle Orthod. July:244-254, 1986.

34. Lindqvist, B. and Thilander, T.: Extraction of third molars in cases of anticipated crowding in the lower jaw. Am. J. Orthod. 81:130-139, 1982.

35. Ades, A.G., Joondeph, D.R., Little, R.M., and Chapko,

M.K.: A long-term study of the relationship of third molars to changes in the mandibular dental arch. Am. J. Orthod. Dentofac. Orthop. 97:323-325, 1990.

36. Kaplan, R. G.: Mandibular third molars and postretention crowding. Am. J. Orthod. 66:411-430, 1974.

37. Vasir, N. S. and Robinson, R. J.: The mandibular third molar and late crowding of the mandibular incisors - a review. Br. J. Orthod. 18:59-66, 1991.

38. Sampson, W. J., Richards, L.C., and Leighton, B.C.: Third molar eruption patterns and mandibular dental arch crowding. Aust. Ortho. J. 8:10-20, 1983.

39. Osborn, J.W.: An investigation into the interdental forces occurring between teeth of the same arch during clenching the jaws. Arch. Oral Biol. 5:202-211, 1961.

40. Southard, T.E., Behrents, R.G., and Tolley, E.A.: The anterior component of occlusal force. Am. J. Orthod. Dentofac. Orthop. 96:493-500, 1989.

41. Southard, T.E., Behrents, R.G., and Tolley, E.A.: The anterior component of occlusal force. Part 2. Relationship with dental malalignment. Am J. Orthod. Dentofac. Orthop. 97:41-44, 1990.

42. Little, R.M.: The irregularity index: A quantitative score of mandibular anterior alignment. Am. J. Orthod. 68:554-563, 1975.

43. Southard, T.E., Southard, K.A., and Tolley, E.A.: Variation of approximal tooth contact tightness with

postural change. J. Dent. Res. 69:1776-1779, 1990.

44. Bishara, S. E. and Andreason, G.: Third molars: A review. Am. J. Orthod. 83:131-137, 1983.

45. Bramante, M. A.: Controversies in orthodontics. Dent. Clin. North Am. 34:91-102. 1990.

46. Nolla, C.: Development of the permanent teeth. J. Dent. Child. 27:254-263, 1960.

47. Weinstein, S., Haack, C.H., Morris, L.Y., Snyder, B.R., Attaway, H.E.,: On an equilibrium theory of tooth position. Angle Orthod. 33:1-26, 1963.

48. Weinstein, S.: Minimal forces in tooth movement. Am. J. Orthod. 53:881-903, 1967.

49. Richardson, M., Mills, K.: Late lower arch crowding: the effect of second molar extraction. Am. J. Orthod. Dentofac. Orthop. 98:242-246, 1990.

50. Proffit, W.R. Equilibrium theory revisited: factors influencing position of teeth. Angle Orthod. 48:175-186, 1978.

51. Berkovitz, B. K.: The effect of root transection and partial root resection on the unimpeded eruption of the rat incisor. Arch. Oral Biol. 16:1033-1043, 1971.

52. Bjork, A. and Palling, M.: Adolescent age changes in sagittal jaw relations, alveolar prognathy, and mesial inclination. Acta Odont. Scan. 12:201-232, 1955.

53. Korber, K. H.: Periodontal Pulsation. J. Periodont. 41:686-708, 1970.

APPENDIX A

Consent Form

Consent Form

This study is being conducted to evaluate the amount of force that developing wisdom teeth may generate in the lower dental arch. All treatment procedures in this study are normal treatment protocol independently deemed necessary by your orthodontist/oral surgeon. The only extra procedure made necessary by this study involves the drawing of a thin (.015 inch) strand of stainless steel between the contact points of four lower teeth. This procedure, akin to pulling a piece of dental floss between the teeth, occurs well above the gum line. The total test time required will be but a few minutes.

You will be tested twice prior to having your wisdom teeth removed in your oral surgeons office. The last two identical test will be performed approximately 1 and 2 then months later.

Your identity as a patient will be kept in strict confidence. Information obtained by this study will only be used for educational and research publication purposes. You are under no obligation to comply with this study and are free to discontinue your participation at any time.

Information gained in this study will contribute to our overall understanding of orthodontic retention and treatment stability.

I shall be happy to answer to answer any questions or concerns you may have regarding this study. Please contact myself (Dr. Al Graas) at 492-3065.

Thank you for your interest and cooperation in this study.

After having had the above study explained to me, and having read the above letter, I hereby consent to participate in this study.

Date _____ _____
Name of Participant (printed)

Witness _____ _____
Name of person authorized to sign on behalf of participant (printed)

_____ _____
Signature Date

APPENDIX B

Interproximal Contact Force Calculation

When dry tooth contacts are separated by the introduction of a length of shim-stock (Figure 4) between them[31] a recoil force R is exerted on each side of the band. If the band is pulled with a force P in the direction indicated there is a frictional force f opposing withdrawal. When P is increased until movement just occurs then

$$P = f$$

$$f = 2\mu R$$

where μ is the coefficient of friction between tooth and band. Therefore

$$P = 2\mu R$$

P can be measured with a load cell and μ can be determined by experiment(30,31). Thus it is possible to calculate R, the recoil or interproximal contact force as

$$IPF = f/2\mu \quad \text{(Newton)}$$

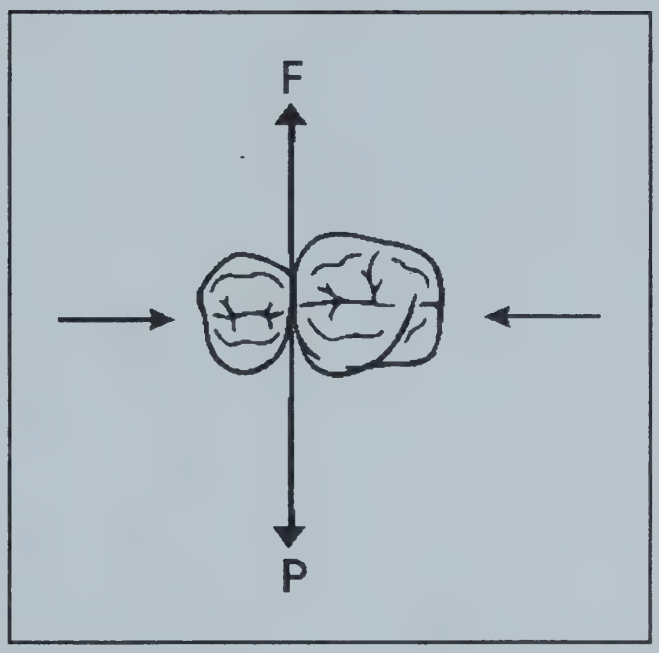

Diagram of occlusal view of two premolars with band inserted between them showing the forces acting on the band during withdrawal.

Figure 6

APPENDIX C

Calibration Data

- Static Loading

- In Vitro Testing

Static Load Calibration

Calibration Runs for f = 0 - 1000 gms

Known Weight (gms)	0	300	500	700	1000	
Recorded Weight (gms)	0	303	503	700	1000	Run 1
	0	303	503	698	1000	Run 2
	0	302	502	700	1000	Run 3

Calibration Runs for f = 0 - 400 gms

Known Weight (gms)	0	100	200	300	400	
Recorded Weight (gms)	0	98	198	299	400	Run 1
	0	98	198	299	400	Run 2
	0	98	198	299	400	Run 3

Calibration Runs for f = 0 - 200 gms

Known Weight (gms)	0	50	100	150	200	
Recorded Weight (gms)	0	49	99	149	200	Run 1
	0	49	99	149	200	Run 2
	0	49	99	149	200	Run 3

In Vitro Measurement Technique Reproducibility

Articulator Testing - each test represents 3 successive pull motions as used in vivo

Run 1 0 Grams plus Upper Member Total Weight = 230 gms

Test A - f=64	Test B - f=65	Test B - f=67
- f=64	- f=65	- f=65
- f=64	- f=65	- f=65

Run 2 500 Grams plus Upper Member Total Weight = 730 gms

Test A - f=198	Test B - f=195	Test C - f=196
- f=198	- f=198	- f=197
- f=196	- f=198	- f=198

Run 3 1000 Grams plus Upper Member Total Weight = 1230 gms

Test A - f=355	Test B - f=354	Test C - f=355
- f=359	- f=357	- f=359
- f=360	- f=358	- f=356

APPENDIX D

Coefficient of Friction Determination Data

Determination of μ

IPF represents the known weight compressing the interdental contact point and f is the force recorded on withdrawal of the stainless steel strip.

Test 1	Test 2	Test 3	Test 4
IPF = 230	IPF = 230	IPF = 730	IPF = 730
f = 65	f = 67	f = 202	f = 210
u = .141	u = .146	u = .138	u = .144

Test 5	Test 6
IPF = 430	IPF = 430
f = 128	f = 127
u = .149	u = .148

Mean - .14533

S.D. - .002

APPENDIX E

Data

Following is a listing of calculated IPF values for each subject for each time. To convert the calculated IPF values to the actual f values recorded multiply the IPF value by 0.290.

Subject		T_1	T_2	T_3	T_4
1.	R=	114.9	131.0	40.2	106.9
	L=	13.8	18.3	0.0	0.0
2.	R=	308.6	350.6	193.1	260.9
	L=	271.3	309.2	0.0	143.7
3.	R=	1444.8	1410.3	1123.0	1095.4
	L=	1381.6	1464.4	947.1	994.2
4.	R=	496.6	456.3	255.2	372.4
	L=	123.0	69.0	42.5	86.2
5.	R=	260.9	266.7	200.0	379.3
	L=	212.6	218.4	312.6	427.6
6.	R=	586.2	528.7	188.5	217.2
	L=	435.6	494.3	220.7	283.9
7.	R=	767.8	713.8	571.3	489.7
	L=	731.0	989.7	255.2	279.3
8.	R=	215.3	219.4	210.3	218.4
	L=	175.4	172.4	178.2	178.2
9.	R=	152.9	162.1	110.3	151.7
	L=	233.3	239.1	89.7	172.4
10.	R=	515.0	544.8	519.5	458.6
	L=	686.2	665.2	665.2	541.4
11.	R=	760.9	822.9	118.3	503.4

Subject		T_1	T_2	T_3	T_4
	L=	667.7	737.9	173.6	355.2
12.	R=	805.8	784.4	597.7	782.7
	L=	772.4	801.1	826.4	612.6
13.	R=	232.2	206.9	31.0	83.9
	L=	308.2	317.2	120.7	205.8
14.	R=	3678.2	3459.1	2706.9	2620.7
	L=	1593.0	1401.6	833.3	827.0
15.	R=	365.5	342.5	166.7	282.8
	L=	403.5	444.8	258.6	626.4
16.	R=	687.4	672.4	239.1	286.2
	L=	297.7	252.9	125.3	113.8
17.	R=	456.3	527.6	318.4	341.4
	L=	470.1	628.7	478.2	457.0
18.	R=	93.1	55.2	0.0	0.0
	L=	700.0	510.3	231.0	443.7
19.	R=	747.1	483.9	423.0	412.6
20.	R=	432.2	382.8	300.0	400.0
	L=	105.8	124.1	63.2	175.9
21.	R=	1258.2	1448.3	593.0	775.8
	L=	895.2	879.3	370.0	275.9
22.	R=	486.2	544.8	72.4	413.8
	L=	597.7	490.8	221.8	255.2
23.	R=	546.0	590.8	348.3	457.5
	L=	579.0	623.0	365.5	429.9
24.	R=	381.2	372.4	320.7	259.8

Subject		T_1	T_2	T_3	T_4
	L=	513.8	426.4	341.7	264.4
25.	R=	627.6	816.1	487.3	503.5
	L=	536.8	908.1	644.8	344.8
26.	R=	751.7	641.4	54.0	44.8
	L=	879.3	798.9	225.3	251.7
27.	R=	1132.2	1064.4	1196.6	388.5
	L=	833.3	767.8	875.9	417.2
28.	R=	646.0	697.7	463.2	378.2
	L=	689.2	582.8	611.5	467.8
29.	R=	718.4	685.7	558.6	543.4
	L=	817.2	850.3	570.1	534.5

Following is a tabulation of the independent variables for each subject for age, gender (Gen.=gender), angle of impaction (Angle-right and left), Nolla stage of root development (Nolla-right and left), depth of impaction (Depth in mm.-right and left), history of orthodontic treatment (Orhto-yes or no), a listing of missing teeth in the mandibular arch (Miss), and surgeon (Surg).

			Angle		Nolla		Depth				
Subject	Age	Gen.	R	L	R	L	R	L	Ortho	Miss	Surg
1.	19-1	F	72	80	8	8	2	4	N	-	S
2.	18-5	M	25	32	9	9	8	8	N	-	T
3.	20-9	M	40	5	8	8	12	15	N	4/4	S
4.	22-8	F	78	86	9	9	3	1	N	-	S
5.	15-6	M	41	40	7	7	6	6	Y	4/4	T
6.	16-6	M	62	68	9	9	2	2	N	-	S
7.	17-4	F	59	56	8	8	4	8	N	-	S
8.	17-3	F	57	55	7	7	8	9	Y	/3	K
9.	17-10	M	80	15	8	8	8	8	Y	4/4	T
10.	19-6	F	40	82	9	9	5	1	Y	4/4	T
11.	19-11	F	50	45	7	7	8	10	N	-	S
12.	17-0	F	69	68	9	9	3	3	Y	-	S
13.	16-9	M	42	35	6	6	3	3	Y	/1	K
14.	18-10	M	15	40	8	8	8	8	N	-	T
15.	19-1	F	30	40	9	9	7	7	N	-	T
16.	20-11	F	87	32	9	9	1	9	N	-	T
17.	18-10	M	19	63	9	9	7	5	N	-	S

Subject	Age	Gen.	Angle R	Angle L	Nolla R	Nolla L	Depth R	Depth L	Ortho.	Miss.	Surg.
18.	19-6	F	28	32	9	9	7	9	N	-	S
19.	21-4	F	58	-	9	-	6	-	N	-	S
20.	17-3	F	82	68	8	8	1	1	Y	4/4	S
21.	22-8	F	60	13	9	9	4	7	N	-	S
22.	15-11	M	47	64	8	8	7	6	Y	-	S
23.	19-5	F	45	48	7	8	10	10	Y	-	T
24.	22-1	F	55	48	9	9	8	10	N	_	S
25.	20-0	F	52	52	8	8	10	10	Y	4/4	S
26.	22-9	F	58	44	9	9	7	11	Y	-	S
27.	19-11	F	42	52	9	9	9	5	N	/1	S
28.	21-0	F	29	27	7	7	11	14	N	-	S
29.	19-3	F	72	75	8	8	10	10	N	-	T

APPENDIX F

Pearson Correlation Coefficients

- - - - - - - - - - - - - - PEARSON CORRELATION COEFFICIENTS - - - - - - - - - - - - - -

	R1	R2	R3	R4	AGE	RANGLE	RNOLLA	RDEPTH	SEXX	ORTHX	L1
	1.0000	.9908	.9435	.9481	.1777	-.2957	.0584	.2478	-.1722	-.2662	.8045
	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(28)
	P= .	P= .000	P= .000	P= .000	P= .178	P= .060	P= .382	P= .098	P= .186	P= .081	P= .000
	.9908	1.0000	.9321	.9502	.1848	-.3102	.0377	.2735	-.1729	-.2507	.8066
	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(28)
	P= .000	P= .	P= .000	P= .000	P= .169	P= .051	P= .423	P= .076	P= .185	P= .095	P= .000
	.9435	.9321	1.0000	.9269	.0990	-.3405	.0521	.3101	-.1579	-.2445	.7591
	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(28)
	P= .000	P= .000	P= .	P= .000	P= .305	P= .035	P= .394	P= .051	P= .207	P= .101	P= .000
	.9481	.9502	.9269	1.0000	.0294	-.3068	-.0356	.2454	-.2325	-.1708	.7326
	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(28)
	P= .000	P= .000	P= .000	P= .	P= .440	P= .053	P= .427	P= .100	P= .112	P= .188	P= .000
E	.1777	.1848	.0990	.0294	1.0000	.0777	.4030	.2471	.5061	-.4328	.2723
	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(28)
	P= .178	P= .169	P= .305	P= .440	P= .	P= .344	P= .015	P= .098	P= .003	P= .010	P= .080
NGLE	-.2957	-.3102	-.3405	-.3068	.0777	1.0000	.0940	-.6132	.3638	.1734	-.4226
	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(28)
	P= .060	P= .051	P= .035	P= .053	P= .344	P= .	P= .314	P= .000	P= .026	P= .184	P= .013
OLLA	.0584	.0377	.0521	-.0356	.4030	.0940	1.0000	-.1919	.1889	-.3859	.1079
	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(28)
	P= .382	P= .423	P= .394	P= .427	P= .015	P= .314	P= .	P= .158	P= .163	P= .019	P= .292
EPTH	.2478	.2735	.3101	.2454	.2471	-.6132	-.1919	1.0000	.0295	-.1476	.5216
	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(28)
	P= .098	P= .076	P= .051	P= .100	P= .098	P= .000	P= .159	P= .	P= .440	P= .222	P= .002
XX	-.1722	-.1729	-.1579	-.2325	.5061	.3638	.1889	.0295	1.0000	-.0900	-.0824
	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(28)
	P= .186	P= .185	P= .207	P= .112	P= .003	P= .026	P= .163	P= .440	P= .	P= .321	P= .338
THX	-.2662	-.2507	-.2445	-.1708	-.4328	.1734	-.3859	-.1476	-.0900	1.0000	-.2394
	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(28)
	P= .081	P= .095	P= .101	P= .188	P= .010	P= .184	P= .019	P= .222	P= .321	P= .	P= .110
	.8045	.8066	.7591	.7326	.2723	-.4226	.1079	.5216	-.0824	-.2394	1.0000
	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)
	P= .000	P= .000	P= .000	P= .000	P= .080	P= .013	P= .292	P= .002	P= .338	P= .110	P= .

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	R1	R2	R3	R4	AGE	RANGLE	RNOLLA	RDEPTH	SEXX	ORTHX	L1
	.7357	.7530	.7060	.6878	.2166	-.3840	.0710	.5351	-.0773	-.2048	.9483
	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)
	P= .000	P= .000	P= .000	P= .000	P= .134	P= .022	P= .360	P= .002	P= .348	P= .148	P= .000
	.5875	.6032	.7083	.5909	.1338	-.3742	.0937	.5480	.0016	-.0618	.7668
	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)
	P= .001	P= .000	P= .000	P= .000	P= .249	P= .025	P= .318	P= .001	P= .497	P= .377	P= .000
	.5775	.5741	.6346	.6355	.0165	-.5421	.0131	.5658	-.1740	-.1327	.7851
	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)
	P= .001	P= .001	P= .000	P= .000	P= .467	P= .001	P= .474	P= .001	P= .188	P= .250	P= .000
NGLE	-.1126	-.1383	-.0305	-.0372	-.1478	.2563	.1606	-.1077	.1876	.0663	-.1583
	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)
	P= .284	P= .241	P= .439	P= .426	P= .227	P= .094	P= .207	P= .293	P= .170	P= .369	P= .210
OLLA	.0495	.0439	.0486	-.0344	.4028	.0737	.9765	-.1484	.2075	-.3307	.1132
	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)
	P= .401	P= .412	P= .403	P= .431	P= .017	P= .355	P= .000	P= .226	P= .145	P= .043	P= .283
EPTH	.1908	.2122	.1435	.1417	.3837	-.2609	-.2236	.7161	.0831	-.2241	.4530
	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)
	P= .165	P= .139	P= .233	P= .236	P= .022	P= .090	P= .126	P= .000	P= .337	P= .126	P= .008
MISS	-.1251	-.1130	.0473	-.0680	-.3046	.0485	-.3628	-.0057	-.1944	.5509	-.1382
	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(28)
	P= .259	P= .280	P= .404	P= .363	P= .054	P= .401	P= .027	P= .488	P= .156	P= .001	P= .242
IFF	.7864	.7972	.5697	.6113	.3878	-.1544	.1199	.1319	-.0684	-.2877	.6777
	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(29)	(28)
	P= .000	P= .000	P= .001	P= .000	P= .019	P= .212	P= .268	P= .248	P= .362	P= .065	P= .000
IFF	.6297	.6379	.4539	.4934	.3235	-.1583	.0847	.2454	-.0466	-.2715	.7518
	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)	(28)
	P= .000	P= .000	P= .008	P= .004	P= .047	P= .211	P= .334	P= .104	P= .407	P= .081	P= .000

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PEARSON CORRELATION COEFFICIENTS

	L2	L3	L4	LANGLE	LNGLLA	LDEPTH	IPMISS	BDIFF	LDIFF
P1	.7267 (28) P= .000	.6870 (28) P= .001	.5756 (28) P= .001	-.1136 (28) P= .284	.0405 (28) P= .401	.1008 (28) P= .303	-.1251 (28) P= .358	.7884 (28) P= .000	.6307 (28) P= .000
P2	.7630 (28) P= .000	.6093 (28) P= .000	.5761 (28) P= .001	-.1383 (28) P= .241	.0428 (28) P= .413	-.2122 (28) P= .139	-.1130 (28) P= .280	.7873 (28) P= .000	.6378 (28) P= .000
P3	.7020 (28) P= .000	.7083 (28) P= .000	.5266 (28) P= .000	-.0308 (28) P= .438	.0686 (28) P= .363	-.1439 (28) P= .233	.0473 (28) P= .406	.6897 (28) P= .001	.6939 (28) P= .000
P4	.6878 (28) P= .000	.6000 (28) P= .000	.5755 (28) P= .000	-.0772 (28) P= .426	-.0364 (28) P= .427	-.1411 (28) P= .236	-.0680 (28) P= .363	.6113 (28) P= .000	.6826 (28) P= .000
AGE	.2166 (28) P= .134	-.1330 (28) P= .248	.0165 (28) P= .467	-.1478 (28) P= .227	.4026 (28) P= .017	.3677 (28) P= .022	.3046 (28) P= .056	.3878 (28) P= .010	.3235 (28) P= .047
ANGLE	.3866 (28) P= .023	-.5743 (28) P= .025	.5421 (28) P= .001	.2863 (28) P= .004	.0737 (28) P= .355	.2000 (28) P= .050	.0485 (28) P= .401	.1804 (28) P= .213	.1583 (28) P= .21
ANGLLA	.0716 (28) P= .362	.0027 (28) P= 1.0	.0713 (28) P= .474	.1000 (28) P= .307	.5705 (28) P= .000	.3234 (28) P= .120	.3638 (28) P= .057	.1100 (28) P= .368	.0847 (28) P= .334
DEPTH	.5351 (28) P= .002	.5480 (28) P= .001	.5858 (28) P= .001	.1077 (28) P= .293	.1484 (28) P= .224	.7101 (28) P= .000	.0007 (28) P= .488	.1310 (28) P= .348	.2456 (28) P= .106
BDIFF	.0717 (28) P= .348	.0016 (28) P= .497	.1140 (28) P= .281	.1878 (28) P= .170	.3075 (28) P= .105	.0831 (28) P= .337	.1044 (28) P= .300	.0806 (28) P= .343	.0000 (28) P= .497
DIFFS	.3048 (28) P= .058	.0518 (28) P= .397	.1337 (28) P= .250	.0663 (28) P= .368	.2337 (28) P= .063	.3261 (28) P= .126	.5005 (28) P= .007	.3877 (28) P= .035	.3715 (28) P= .051
L	.8402 (28) P= .000	.7888 (28) P= .000	.7881 (28) P= .000	.1667 (28) P= .210	-.32 (28) P= .083	.4830 (28) P= .008	.1383 (28) P= .242	.6777 (28) P= .000	.7016 (28) P= .000

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PEARSON CORRELATION COEFFICIENTS

	L2	L3	L4	LANGLE	LNGLLA	LDEPTH	IPMISS	BDIFF	LDIFF
L2	1.0000 (28) P= .	.7888 (28) P= .000	.7881 (28) P= .000	-.1667 (28) P= .396	.0781 (28) P= .346	.4807 (28) P= .007	-.0887 (28) P= .362	.8084 (28) P= .000	.7016 (28) P= .000
L3	.7888 (28) P= .000	1.0000 (28) P= .	.8263 (28) P= .000	.0765 (28) P= .348	.0983 (28) P= .309	.3990 (28) P= .040	.1666 (28) P= .176	.3990 (28) P= .040	.3390 (28) P= .101
L4	.7881 (28) P= .000	.8263 (28) P= .000	1.0000 (28) P= .	-.0370 (28) P= .426	.0307 (28) P= .436	.3430 (28) P= .037	.0483 (28) P= .368	.3907 (28) P= .046	.3666 (28) P= .027
LANGLE	-.1611 (28) P= .206	.0765 (28) P= .348	-.0370 (28) P= .426	1.0000 (28) P= .	.1813 (28) P= .200	-.6878 (28) P= .000	-.0171 (28) P= .466	-.3861 (28) P= .000	-.3618 (28) P= .000
LNGLLA	.0781 (28) P= .348	.0983 (28) P= .309	.0307 (28) P= .436	.1813 (28) P= .200	1.0000 (28) P= .	-.1878 (28) P= .167	-.3830 (28) P= .030	.1183 (28) P= .276	.0480 (28) P= .333
LDEPTH	.4807 (28) P= .007	.3990 (28) P= .040	.3430 (28) P= .037	-.6878 (28) P= .004	-.1878 (28) P= .167	1.0000 (28) P= .	-.1660 (28) P= .239	.3705 (28) P= .053	.4316 (28) P= .011
IPMISS	-.0887 (28) P= .362	.1666 (28) P= .176	.0483 (28) P= .368	-.0171 (28) P= .466	-.3830 (28) P= .030	-.1660 (28) P= .239	1.0000 (28) P= .	-.3278 (28) P= .037	-.3377 (28) P= .038
BDIFF	.8084 (28) P= .000	.3990 (28) P= .040	.3907 (28) P= .040	-.3861 (28) P= .024	.1183 (28) P= .276	.3705 (28) P= .053	-.3278 (28) P= .037	1.0000 (28) P= .	.7876 (28) P= .000
LDIFF	.7876 (28) P= .000	.3390 (28) P= .101	.3666 (28) P= .027	-.3618 (28) P= .000	.0480 (28) P= .333	.4316 (28) P= .011	-.3377 (28) P= .038	.7876 (28) P= .000	1.0000 (28) P= .

(COEFFICIENT / (CASES) / 1-TAILED SIG) "." IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED

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